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# ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES

Report [illegible]

[illegible] FOAM STUDIES

Project [illegible]

[illegible] April 19[illegible]

(Revised 1 March 19[illegible])



DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
ENGINEER RESEARCH
AND DEVELOPMENT LABORATORIES
THE ENGINEER CENTER
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ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES

Report 1166

# FOG FOAM STUDIES

Project 8-76-01-001 (9)

2 April 1950

(Revised 1 March 1951)[1]

Submitted to

Navy Department Bureau of Aeronautics

Through

THE CHIEF OF ENGINEERS, U. S. Army

by

The Commanding Officer
Engineer Research and Development Laboratories

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1. Appendix II, is bound under separate cover.

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## SUMMARY

Subject. This report covers tests conducted by the Engineer Research and Development Laboratories as requested by the Department of the Navy. Funds were provided by the Bureau of Aeronautics for the ERDL to determine the effect of hydraulic pressure on the fire extinguishing characteristics of fog foam; and to determine experimentally standards of performance for fog foam nozzles.

Investigation. Performance tests were conducted with all the fog foam nozzles under consideration and subsequently, fire tests were made with several nozzles having various percent foam yields. The fire tests were carried out for the purpose of comparing, correlating, and evaluating the performance tests results with the actual test fires. Throughout the entire investigation, the foam solution contained 6 percent of foam liquid by volume. From these studies, standard procedures in using different types of fog foam appliances were developed. The nozzles which produced the highest foam yields and had the most effective nozzle pressures for use in fire fighting were ascertained.

Conclusions. The report concludes that the fire extinguishing effectiveness of fog foam nozzles is indicated by these standards: (1) foam yield percent; (2) rate of application; and (3) water content of foam (6 to 9 expansion) output in gallons per minute. The test procedure set forth in the screening tests (par. 18) is a satisfactory means of evaluating the fire fighting effectiveness of fog foam nozzles. On the bases of the foam used and the nozzles employed, the most effective nozzle pressure was between 200 and 300 psi. Aspirating type nozzles produced higher foam yields than did the non-aspirating type.

Recommendations. The report recommends that the standards of performance and the test procedures (pars. 17 and 18) be adopted by the Department of National Defense for use in the design of fog foam nozzles and in their evaluation for fire fighting.

# FOG FOAM STUDIES

## I. INTRODUCTION

1. Subject. This report covers tests conducted by the Engineer Research and Development Laboratories as requested by the Department of the Navy. Funds were provided by the Bureau of Aeronautics for the ERDL to accomplish the following:

a. Determine the effect of hydraulic pressure on the fire extinguishing characteristics of fog foam.

b. Determine experimentally standards of performance for fog foam nozzles.

2. Authority. The authority for conducting this investigation is contained in the following:

a. Letter from the Chief of Engineers to the Engineer Research and Development Laboratories, file ENGNC, dated 3 January 1949, subject: Test of Fog Foam for Airplane Crash Fire Fighting (Project 8-76-01-001, Authorized Investigations, Fire Fighting).

b. Interdepartmental Government Order from the Bureau of Aeronautics, Department of the Navy to the Corps of Engineers, Department of the Army, dated 2 December 1948, subject: ORDER NAer 00806. APPROP'N 1791502.003, Aviation Navy 1949, Acct. 39831, Bureau Control No. 61000, Program 361A.

c. Letter from Department of the Navy, Bureau of Aeronautics, Washington, D. C. to the Engineer Research and Development Laboratories, file 45576, Aer-SE-31, (15 June 49) dated 15 June 1949, subject: Fogfoam for Fire Extinguishment - Evaluation of.

d. Letter from Department of the Navy, Bureau of Aeronautics, Washington, D. C. to the Engineer Research and Development Laboratories, file 50213, Aer-SE-31, NAER-00806, (30 June 49) dated 30 June 1949, subject: Test of Fog Foam for Airplane Crash Fire Fighting (Project 8-76-01-001, Authorized Investigations, Fire Fighting).

e. Letter from Department of the Navy, Bureau of Aeronautics, Washington, D. C. to the Engineer Research and Development Laboratories, file 95468, Aer-SE-31, (22 Sep 49) dated 22 September 1949, subject: Fog Foam for Fire Extinguishment - Evaluation of.

f. Letter from Department of the Navy, Bureau of Aeronautics, Washington, D. C. to the Engineer Research and Development

Laboratories, file 214956, Aer-SE-31 (2 Dec 49) dated 2 December 1949, subject: Fog Foam for Fire Extinguishment - Evaluation of.

Copies of these letters appear in Appendix II to this report.

3. Terminology. The following definitions describe technical terms used in the report:

a. Water fog. A finely divided spray of water.

b. Foam liquid. A concentrated hydrolized protein liquid conforming to Specification JAN-C-266, 5 August 1946, entitled "Mechanical Foam, Type 5."

c. Foam solution. A dilute water solution of foam liquid.

d. Foam. An aerated mass of bubbles generated from the foam solution.

e. Fog foam. Foam in spray form discharged from a water fog nozzle.

f. Expansion. The ratio of the volume of foam to the volume of foam solution from which it was produced.

g. Breakdown. The collapse of the foam.

h. Drainage. Volume of foam solution separating from a given volume of foam.

i. Drainage rate. The average volume in cubic centimeters of foam solution drained per minute from the first to the fourth minute after the sample was collected.

j. Twenty-five percent drainage time. The time required for drainage of one quarter of the foam solution from the foam. This criterion was developed by the Naval Research Laboratory, Washington, D. C.[1]

k. Stability. The resistance of foam to breakdown.

l. Foam pattern. The actual ground area covered by falling foam as expelled from the nozzle.

1. Naval Research Laboratory, Engineering Research Section, Chemistry Division, Report on Foam Standardization Methods, 26 April 1948.

184-3-108

Fig. 1. Burning Field was subdivided into three test sites: A, water fog screening site; B, fog foam screening test site; and C, fire test site.

m. Foam blanket. The total ground area covered by falling and flowing foam at the end of a specified time interval.

n. Foam yield. Percent ratio of the measured foam volume to the theoretical or calculated foam volume. It is calculated as follows:

$$FY\ (\%) = \frac{V_p}{(V_s)\ (E_a)} \times 100$$

where

$V_p$ = Volume of foam pattern

$V_s$ = Volume of foam solution

$E_a$ = Average expansion

This term is synonymous with nozzle efficiency in converting foam solution into foam.

o. Theorethical foam volume. The volume of foam calculated by multiplying the quantity of the foam solution used by the average expansion.

p. Nozzle pattern. The included angle of discharge.

4. Background. The primary objective of airplane crash fire and rescue operations is to save life. To accomplish this purpose as rapidly as possible and with minimum risk it is necessary to utilize agents which quickly reduce the intensity of the fire; prevent developments of, or reduce high temperatures within, the aircraft; and provide protective atmosphere for personnel and equipment during rescue operations. Until quite recently water fog and carbon dioxide were used almost exclusively for the purpose, singly or in combination. However, these agents provide no protection against reignition and are rapidly losing favor to mechanical foam, especially for rescue of victims from large aircraft.

Mechanical foam applied as a solid stream to a gasoline fire has immediate extinguishing effect but does not provide the necessary protection for personnel and equipment during rescue operations. On the other hand, mechanical foam applied as a spray extinguishes, affords protection against reignition, cools, and provides a safe working atmosphere for the fire fighting personnel.

Most of the foam crash trucks presently in use are converted water fog trucks which were designed for pump pressures ranging from 500 to 800 psi.

184-3-309

Fig. 2. Test area prepared for screening tests. Stakes and buckets on ground are placed 10 feet on centers in an area 180 feet wide by 110 feet deep. Class 155 crash truck mounting water fog nozzle 12 feet above ground is parked in proper testing position. At extreme right is flowmeter foam proportioner assembly mounted on two-wheel trailer.

No previous studies have been made to determine the true function of limits of water pressure at the nozzle itself, in generating and spreading fog foam. It has been suspected for some time that with water fog nozzles the foam decreased in quality at higher pressures. The optimum pressure at which the best quality fog foam was produced had not been determined prior to this investigation.

5. Personnel. R. C. Navarin, Project Engineer, Fire Apparatus Section, supervised the tests which were conducted under the direction of James M. Hayden, supervisor, Fire Equipment Test Area, Eebee Field, assisted by the following test fire fighters: Frank Chudacek, James L. Allen, Conrad Korzendorfer, Charles W. Dean, Edward Marosy, Chester F. Owenby, Carroll Mahon, and Edgar Helms.

Consultation on the project was provided by J. E. Malcolm, Chemical Engineer, Fire Apparatus Section.

## II. INVESTIGATION

6. General. The overall plan of the tests was directed toward the two objectives listed in paragraph 1 of the introduction. The first objective, to determine the effect of hydraulic pressure on the fire extinguishing characteristics of fog foam, was accomplished by conducting initial performance tests of all the nozzles under consideration, and was followed by large-scale pool fire tests with selected nozzles to verify the results of these tests.

The second objective, to develop standards of performance for fog foam nozzles, was attained on the basis of an evaluation of those factors found during the investigation to have a critical effect on nozzle performance.

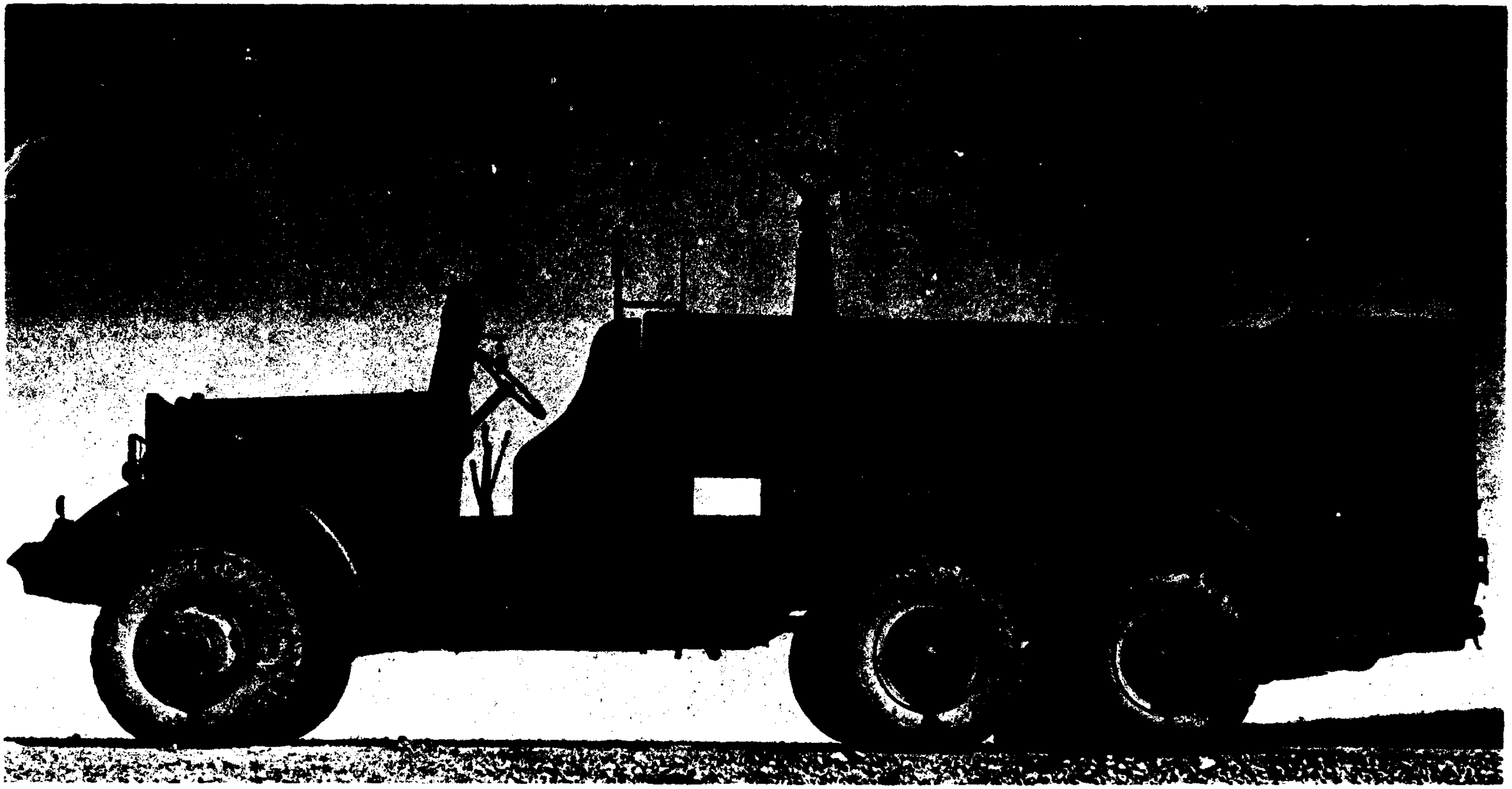
In order to accomplish these objectives, it was necessary to determine the performance of different types of fog foam appliances at various pressures, and to develop standard test procedures which would give reproducible results.

Throughout the investigation, the type of foam liquid remained the same, the foam solution containing 6 percent of foam liquid by volume. Protein base (JAN-C-266) foam liquid was used.

7. Nozzles Tested. The nozzles selected for these tests included representative types for the production of fog foam, foam, and water fog. Some of these are currently in use, while others are experimental models. The following types are represented:

a. External impinging jets, solid cone.

b. Internal impinging jets, solid cone.



184-3-726

Fig. 3. Class 155 crash fire truck used for fog foam tests. This vehicle is powered by Hercules engine, Model HXD, rated at 200 hp at 2150 rpm. Pumping unit consists of Hale centrifugal pump, Model ZEY, with maximum capacity of 325 gpm at 500 psi operated by Continental engine, Model R-602, rated at 225 hp at 3100 rpm.

c. Centrifugal hollow cone.

d. Adjustable hollow cone.

e. Straight stream aspirating with fan-shaped diffusor.

f. Adjustable hollow cone with aspirator.

A complete description of the nozzles which were tested is presented in Appendix II.

8. General Test Conditions and Facilities. Weather conditions were a major factor affecting the final results since the tests were carried out over a period of one year. Therefore, no tests were conducted when the wind velocity was over 8 mph, when rain was falling, or when the ambient temperature was below freezing. The test area and equipment used are described in the following subparagraphs:

a. Test Area. The Burning Field is an area of approximately 100 acres located on the outer boundary of Fort Belvoir. It is equipped to handle all types of fire tests of equipment ranging from hand-operated extinguishers to large mobile units having an output of approximately 2000 gpm of foam.

In order to permit an extensive variety of tests, the area is subdivided into several test sites. For the purpose of this investigation one large section of the Burning Field was laid out into three test sites as follows: water fog, fog foam, and burning pools (Fig. 1). A closeup of the fog foam site is show in Fig. 2.

To facilitate measurement of the foam blanket and pattern, an area 180 feet wide by 110 feet deep was marked out with stakes at 10-foot intervals in order to form the grid (Fig. 2).

b. Equipment Used in Tests. A list of equipment used to conduct the fog foam tests follows:

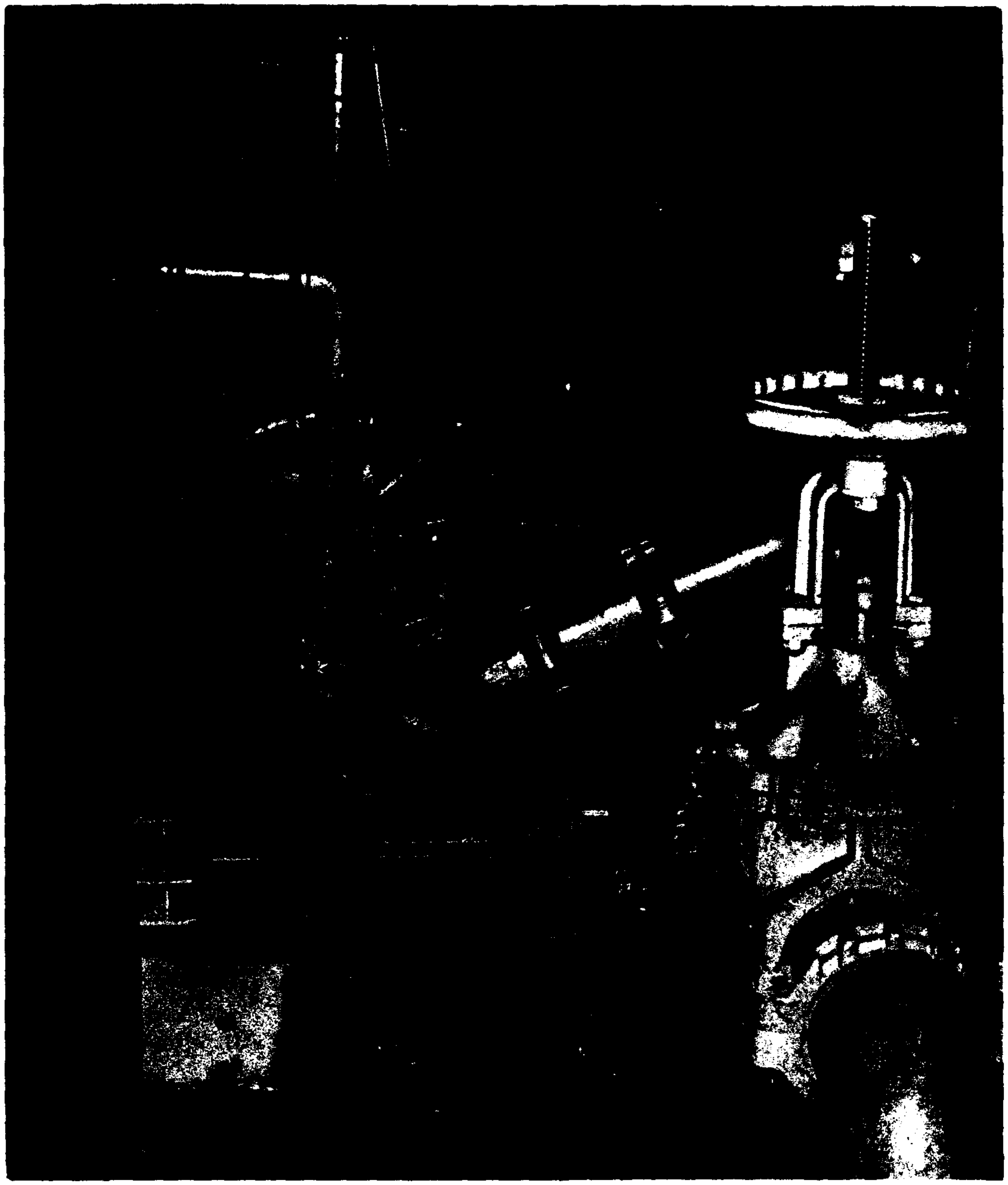
(1) Class 155 crash fire truck fitted with pumping equipment having rated capacity of 300 gpm at 500 psi (Fig. 3).

(2) $2\frac{1}{2}$-inch double-jacket rubber-lined fire hose in 50-foot lengths.

(3) Two Schutte and Koerting Universal Rotometer flowmeters with respective capacities of 250 and 500 gpm.

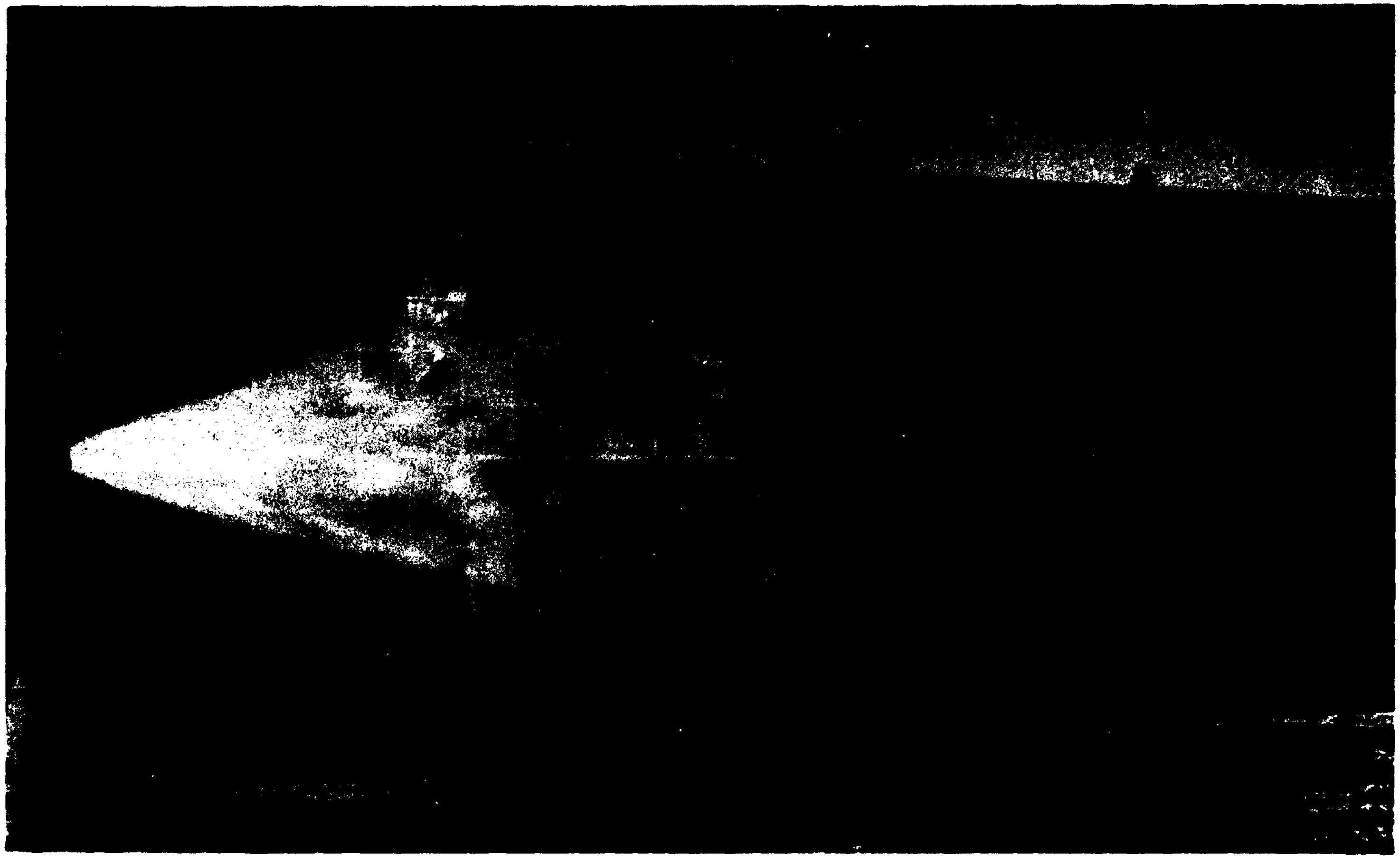
184-3-729

Fig. 4. Flowmeters and foam proportioning equipment assembly mounted on two-wheel trailer. Flowmeters were connected to main water line with manifold for quick interchangeability. Foam proportioners necessitated complete removal and replacement into main water line.



184-3-727

Fig. 5. Stationary pump unit, comprised of Hale centrifugal pump with capacity of 750 gpm at 125 psi, driven by Hall Scott horizontal engine, Model 136, rated at 140 hp at 2800 rpm, supplying pressure in water system at test area.



184-3-469

Fig. 6. Setup of equipment to determine water fog pattern produced by nozzle under test at various pressures. Nozzle discharge has been superimposed on black screen graduated in square feet.

(4) Two Hale foam liquid proportioners with respective capacities of 120 and 500 gpm. Items 3 and 4 were mounted on a two-wheel trailer (Fig. 4).

(5) A stationary unit comprising a Hale centrifugal pump, of 750-gpm capacity at 125 psi, driven by a Hall Scott Model No. 136 horizontal engine, supplied the desired pressure to the water system of the test area (Fig. 5).

(6) Standard laboratory equipment for the evaluation of foam, including graduated cylinders, and glass beakers.

(7) Drainage apparatus consisting of 1400-ml drainage pans 2 inches high by 7 3/8 inches inside diameter with drainage spigot and a drainage stand with 6.5 percent slope.

(8) One anemometer and one hygrometer.

9. Nozzle Performance Tests. Each nozzle in turn was mounted on the turret of the test truck and was tested to determine nozzle pattern, foam yield, foam pattern, drainage rate, and range. Two test sites were set up, water fog and fog foam.

a. Conditions. All nozzles were tested with water alone to determine the nozzle pattern as observed against a vertical grid. For these pattern tests, all the appliances were positioned at the end of the horizontal axis of the vertical grid. Subsequently, the same nozzles were supplied with foam solution at various pressures in order to obtain pertinent data concerning the type of foam produced. For the foam tests, all 2½-inch nozzles were placed on the turret of the test truck and were set 12 feet above the ground in a horizontal position. Bumper type nozzles were similarly mounted 3 feet above the ground and 1½-inch hand lines were placed 4 feet above the ground to simulate actual fire fighting conditions.

b. Procedure. The nozzle performance tests were divided into two phases based on the type of extinguishing agent used, water and foam solution.

(1) Water Tests. In these tests the nozzle pattern was obtained at pressures of from 100 psi to 500 psi for each sample. The nozzle pattern was observed against a vertical grid board (Fig. 6) and a photograph was made of each run. From these photographs the pattern and qualitative fog density was observed for each nozzle and pressure.

(2) Fog Foam Tests. The test equipment was set up as diagrammed in Fig. 7. Unit A represents the equipment

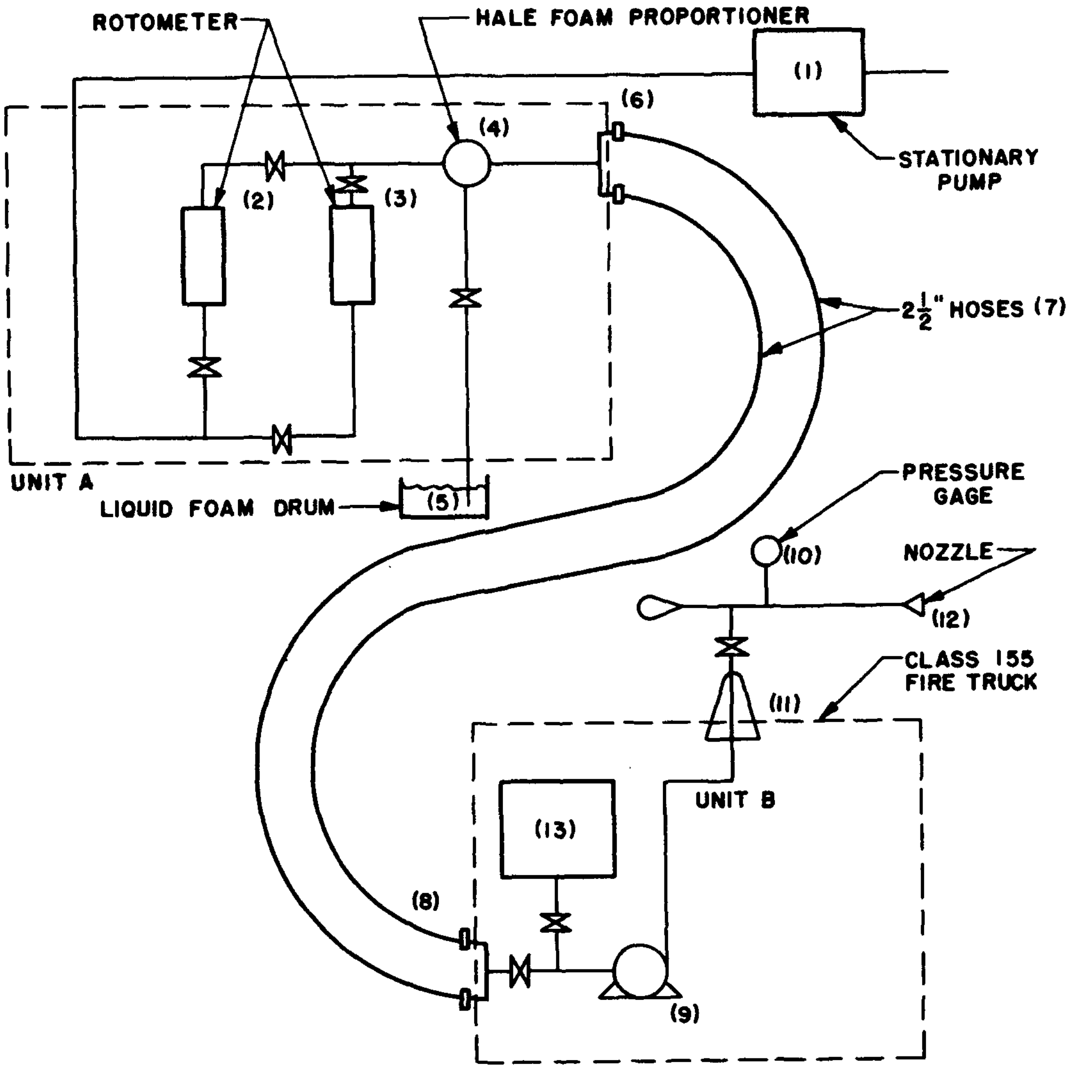
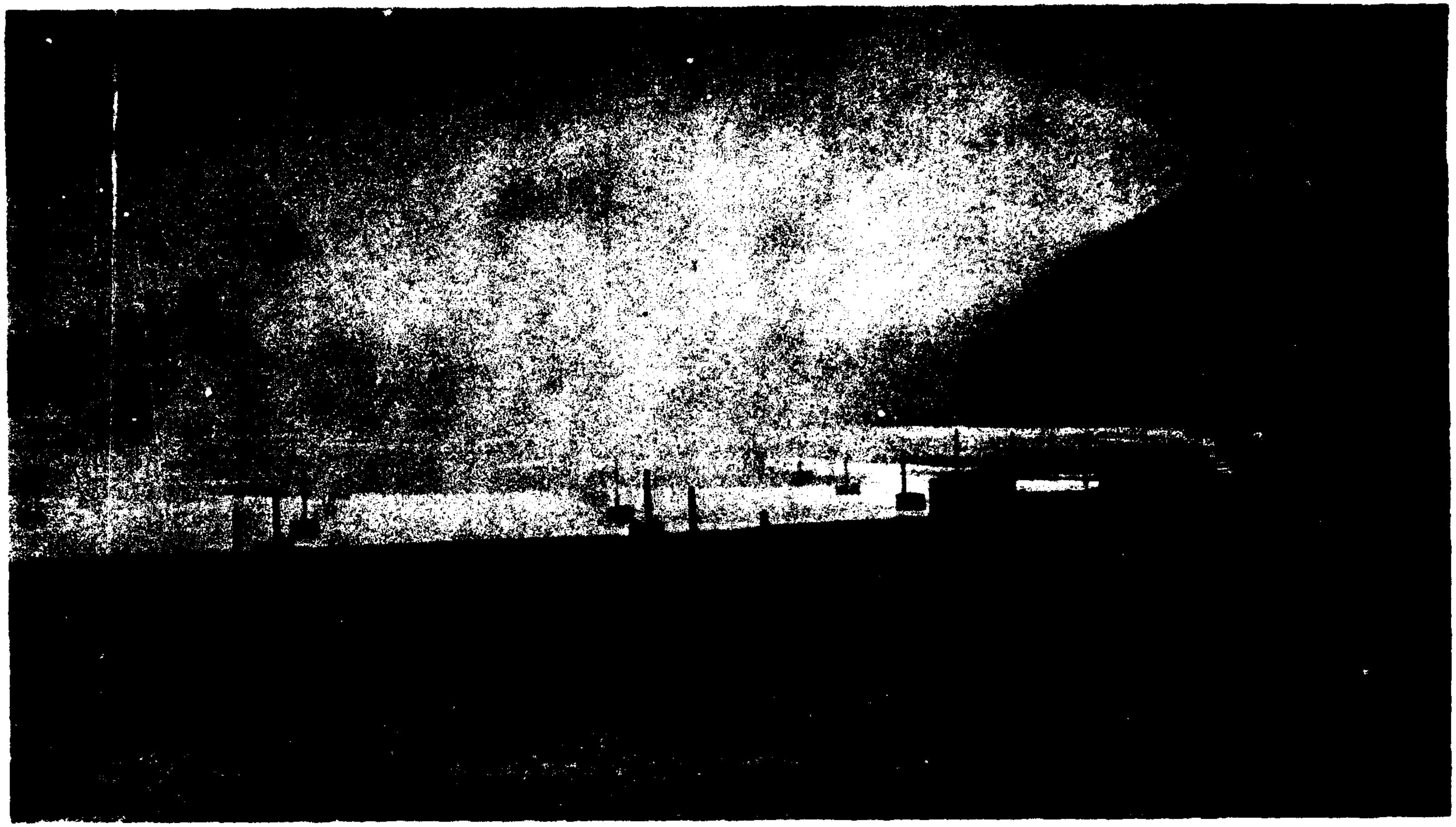



Fig. 7. Fog foam test setup for screening tests.



184-3-307

Fig. 8. Screening test in progress. Note fine fog foam produced by this particular nozzle and observe pattern on ground. Foam was very liquid and drained rapidly. Operator at turret controlled speed of pump in order to obtain even nozzle pressure throughout each test.

184-3-764

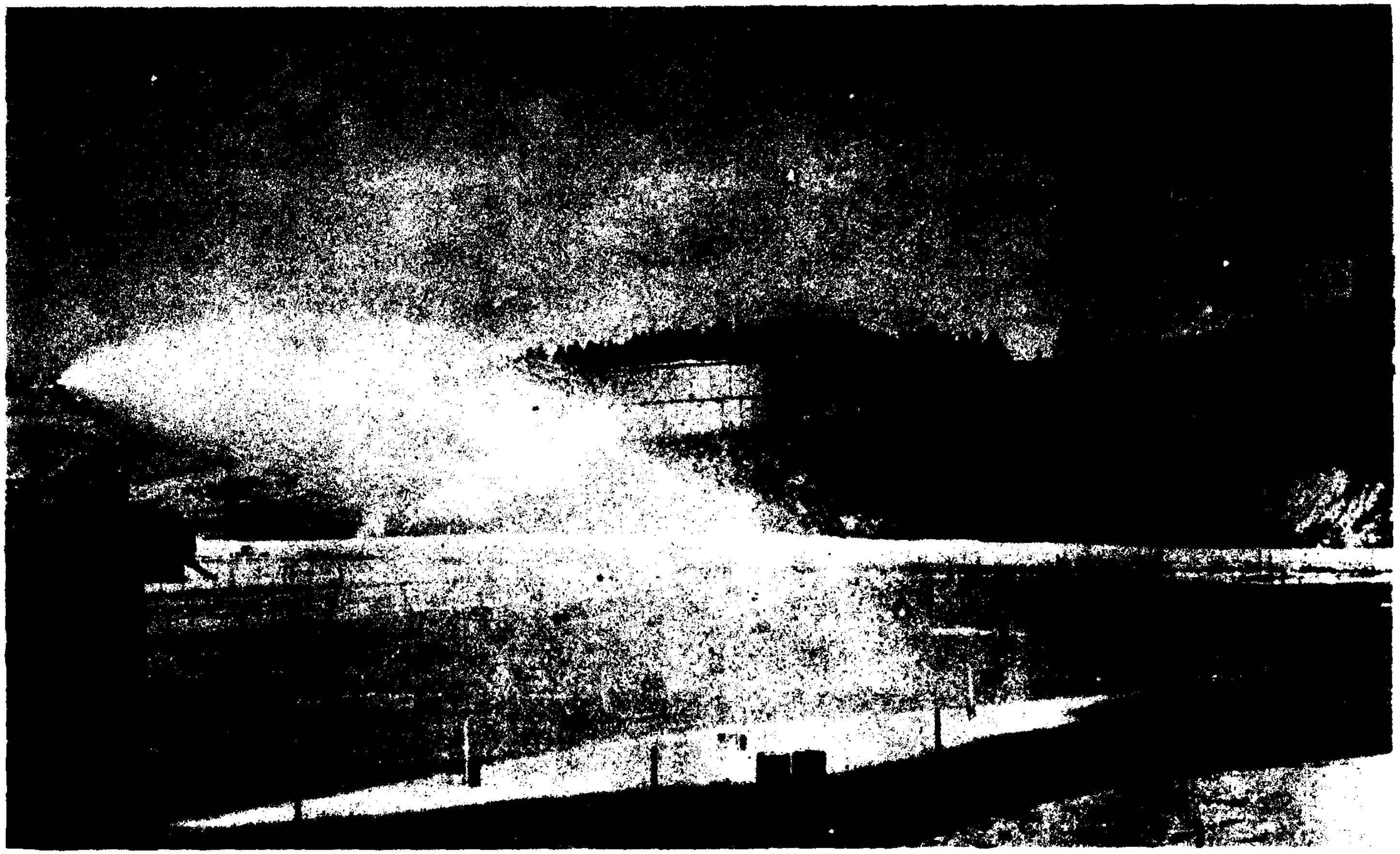
Fig. 9. This screening test was conducted in still air, zero wind velocity. Foam pattern is clearly visible on ground, and its boundaries are well-defined. Note coarse fog foam produced in comparison to that in Fig. 8.

mounted on a trailer, while Unit B represents the equipment on the Class 155 fire truck. During a run, water was pumped from a reservoir by the stationary Hale centrifugal pump (1) through the rotometer (2) or (3) depending on the flow rate, and the Hale foam proportioner (4), either the 120- or 500-gpm model depending on the flow rate, where the foam liquid was picked up from the calibrated drum (5). The foam solution passed through a siamese fitting (6) through $2\frac{1}{2}$-inch fire hoses (7), to a second siamese fitting (8), into the Class 155 fire truck, where the pressure was boosted to the desired value by the pump (9). Pressure was indicated on the gage (10) located on the fixed turret (11). The nozzle (12) discharging the foam solution was mounted on the end of the turret (Figs. 8, 9, and 10). Fig. 11 shows the test area with equipment in place.

The proper rotometer and proportioner for each run was selected and placed in the line. The 120-gpm proportioner had a normal usable range of 60 to 120 gpm, and the 500-gpm proportioner had a range of 250 to 500 gpm. Since no equivalent proportioner was available to cover the range between 120 and 250 gpm, initial tests indicated that the smaller proportioner could also perform satisfactorily in the 120- to 200-gpm range, and that the larger unit could perform similarly in the 200- to 250-gpm range. Runs requiring a discharge of less than 60 gpm made it necessary to premix a 6-percent foam solution in the tank (13) of the Class 155 crash fire truck and all tests so conducted were carried out with Unit B alone (Fig. 7). The delivery rate of the premixed solution was determined by measuring the depth of mixture in the tank before and after each test.

The runs were made for a definite time interval: generally, either for 30 or 60 seconds, depending on the nozzle discharge rate. Before and after each run the level of foam liquid in the calibrated drum was measured. Water flow readings were taken on the rotometer during each run. At the mid point of each test a photograph was taken as a record.

Immediately upon the termination of a run, four men entered the foam area (Fig. 12). Two men were assigned to the drainage rate test, each making a separate determination so that the results could be averaged. Promptness in obtaining the sample was of great importance. Two additional foam samples for the expansion ratio determination were obtained by the third man. While this was being done, the fourth man measured the volume of foam solution collected in the pails within the foam pattern. A fifth crew member (not shown in Fig. 12) measured the foam level in the pails. These individual assignments were necessary because of the rapid change in the foam

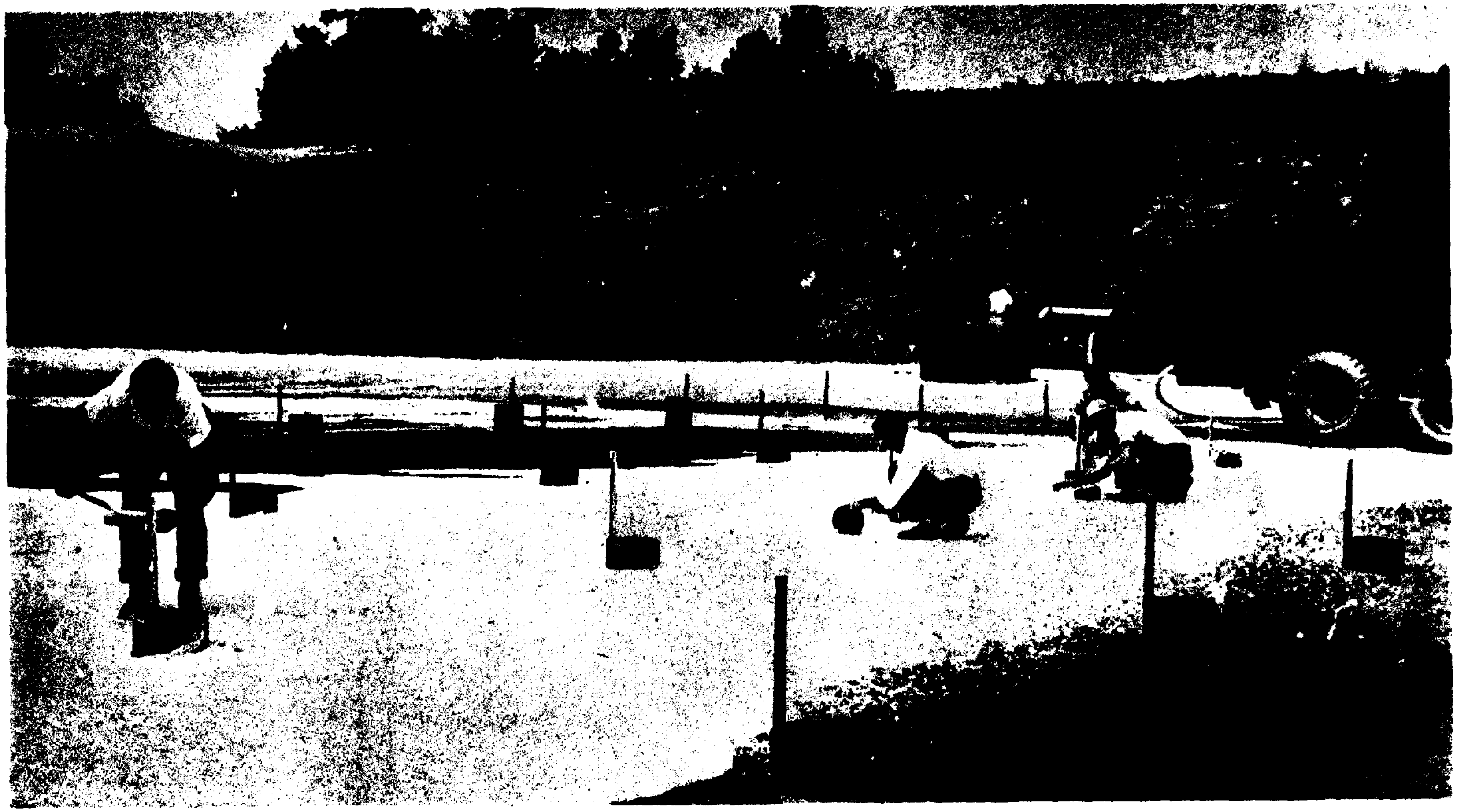


184-3-491

Fig. 10. Nozzle pressure for each test was recorded from gage placed on play pipe directly in back of nozzle.

184-3-236

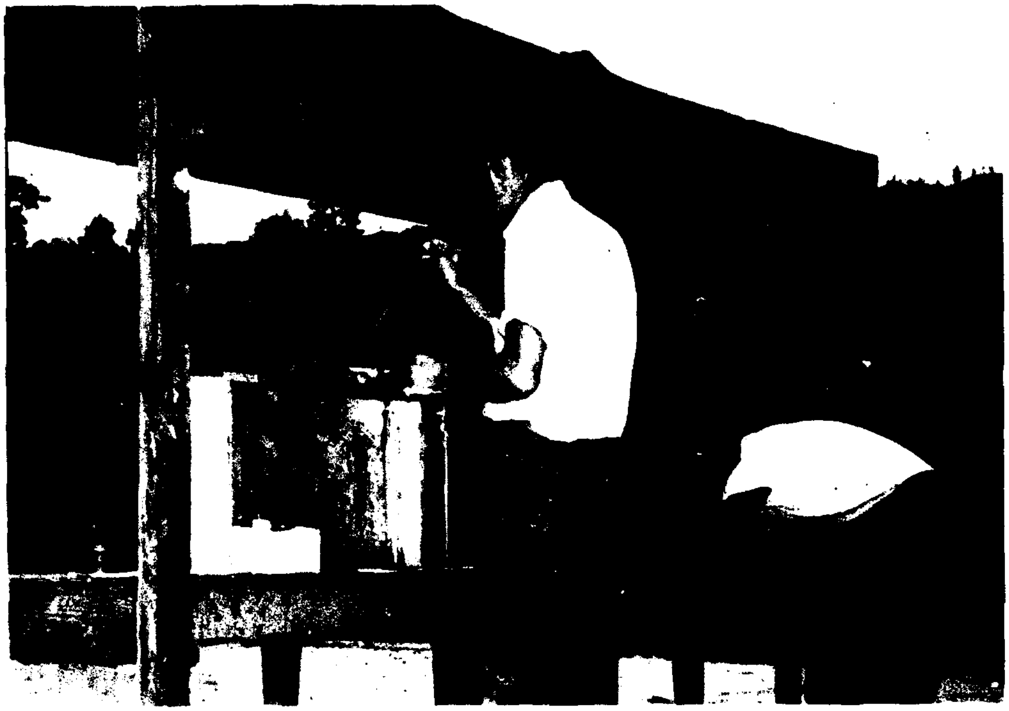
Fig. 11. Screening tests area. During test operation, two $2\frac{1}{2}$-inch fire hose lines were used between Hale foam proportioner and crash fire truck in order to obtain adequate water flow through the system. Large test crew was maintained for these tests so that foam samples could be obtained and test readings could be recorded with least possible delay.



184-3-310

Fig. 12. Test personnel collecting foam samples in drainage pans immediately after completion of test run. In each run, nozzle under test was placed directly above stake in first row to facilitate measuring minor and major axes of pattern formed on ground.

characteristics. The list of calculations used in the fog foam study and a detailed account of the foam test determination procedure are contained in Appendices IA and IB, respectively. The apparatus for both tests is shown in Fig. 13.



184-3-311

**Fig. 13. Foam samples being analyzed to determine expansion and drainage rates of foam produced by nozzles under test. Operator in foreground adds a few drops of octyl alcohol by means of graduated pipette into drainage pan to accelerate breakdown of foam.**

The stakes were used as reference in placing the pans in the area and in recording the foam blanket and pattern. The depth of the foam blanket was measured and recorded at the location of each stake in the blanket. A system of coordinates was used to facilitate a quick identification of each stake (Appendix IC).

**The following data and information were recorded for various pressures from 100 to 500 psi:**

**(a) Foam pattern (coverage) produced by all the nozzles tested.**

(b) Rates of foam solution (consumption).

(c) Foam yields.

(d) Foam expansion.

(e) Drainage rates.

The items listed from (a) through (e) are considered to be determining factors for the proper evaluation of fog foam appliances at any desired pressure.

c. Results. In all, over 200 individual runs were conducted, because of the wide range in pressure and the number of combinations and adjustments of some of the samples.

Sample data sheets indicating the method used to record the desired information are included in Appendix 1C. For more expedient comparison and evaluation, the most pertinent data are listed in Table I. To facilitate cross reference of the data, each nozzle was assigned a number. These appear in column 1 of Table I. The type designation is listed in column 2. Each run was also assigned a number and these are given in column 3.

The pressure for each test which was read directly from a gage at the nozzle is recorded in column 4. The omission of data is an indication that the capacity of the nozzle exceeded the capacity of the test equipment. In order to permit the accumulation of a reasonable quantity of foam for accurate readings, the duration of each run was varied. Column 5 lists the length of time in seconds.

The total water and foam liquid in gallons used for each test run are shown in columns 6 and 7, respectively. The characteristic water flow in gallons per minute for each nozzle at the various pressures is listed in column 8. The concentration of foam liquid is shown in column 9. Close examination of the data indicates that the percent solution, on the average, varied from 5 to 6. The figure in column 9 was derived from columns 6 and 7.

The foam pattern is estimated in feet (column 10). The first reading represents the dimension taken along the axis perpendicular to the flow stream and the second one denotes the measure taken along the axis parallel to the flow stream. The shape of the nozzle and the wind velocity during the test had a variable effect on the data in this column. Column 11 lists the average drainage rates (first to fourth minute after obtaining sample) in cubic centimeters per minute for each nozzle at the various test pressures.

d. Observations. Determinations based on the initial performance tests of all the nozzles are listed in Table II. This table consists of calculations based on field data (Table I) to determine the relative performance of all nozzles tested. Columns 1 through 4 are identical to the corresponding columns in Table I. Column 5 lists the theoretical rates of foam production in gallons per minute at various pressures ranging from 100 to 500 psi inclusive, in 100-lb increments. The actual foam production at these pressures, as measured on the ground, is given in column 6. The foam yield percent, calculated as explained in Appendix IA, is shown in column 7. The latter results are plotted in the form of graphs in Figs. 14 to 18 inclusive, with the foam yield percent along the ordinate axis and the nozzle pressure along the abscissa. Limitations of the test apparatus made it impossible to obtain readings at all pressures with large capacity nozzles. The expansion in column 8 denotes the factor by which the original volume of foam solution was increased with each nozzle at each respective pressure.

The results in the graphs indicate that the highest foam yield was produced at pressures ranging from 200 to 350 psi, depending on the nozzle under test. Generally, the yield either decreased or remained almost constant at pressures higher than 350 psi. Each curve is labeled with the same number in column 1 of Tables I and II and throughout this report to identify the nozzle which it represents, and for quick reference to other tables. The data for each nozzle have been plotted and are clearly shown on the charts. The curve which fitted best through plotted data was drawn as an indication of foam yield percent at the different pressures. The water fog and fog foam tests are shown photographically in Appendices ID and IE.

10. Fire Tests. The second phase of this investigation was to conduct fire tests to validate the findings of the nozzle performance tests. Fire tests were carried out at the Burning Field in an area adjacent to that used in the screening tests (Fig. 19).

a. Nozzles Selected. The seven foam and water-fog nozzles used on actual pool fires were selected from the total of twenty-nine tested on the basis of performance in the initial tests conducted, design of the equipment, and its suitability for crash fire fighting. Nozzles 1, 4a, 4b, 13, and 19 were chosen because the foam yield (Figs. 14 to 18 inclusive) in each case was 45 percent or over, the total water rate of each nozzle was adequate for fighting large-scale inflammable liquid fires. Even though the water rates of nozzles 2 and 3 were comparable to those of the other nozzles under tests, the foam yield was low, that is, below 30 percent (Figs. 15 and 18, respectively). These nozzles were chosen for comparison and evaluation against those having the higher foam yields.

## Table I. Comparison of Field Test Data.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|
| Nozzle No. | Nozzle Type | Run No. | Nozzle Pressure (psi) | Length of Run (sec) | Consumption (gal) Water | Consumption (gal) Foam Liquid | Water Flow (gpm) | Foam Liquid Concentration (%) | Pattern Size (ft) | Avg. Drainage Rate (cc's/min) |
| 1 | 2½-inch external impinging jet | 1 | 100 | 60 | 100 | 6.0 | 100 | 6.0 | 15 x 20 | 17.8 |
| | | 2 | 200 | 60 | 120 | 7.5 | 120 | 6.2 | 15 x 25 | 18.0 |
| | | 3 | 300 | 60 | 150 | 9.0 | 150 | 6.0 | 25 x 30 | 23.5 |
| | | 4 | 400 | 60 | 180 | 9.5 | 180 | 5.5 | 25 x 35 | 17.2 |
| | | 5 | 500 | 30 | 100 | 5.0 | 200 | 5.0 | 20 x 35 | 16.3 |
| 2 | 2½-inch external impinging jet with fan-shaped diffuser | 6 | 100 | 120 | 240 | 13.0 | 120 | 5.4 | 35 x 20 | 15.7 |
| | | 7 | 200 | 120 | 320 | 17.0 | 160 | 5.3 | 15 x 35 | 9.7 |
| | | 8 | 300 | 60 | 170 | 8.0 | 170 | 4.7 | 20 x 25 | 18.5 |
| | | 9 | 400 | 90 | 300 | 14.0 | 200 | 4.6 | 20 x 35 | 21.2 |
| | | 10 | 500 | 60 | 210 | 11.0 | 210 | 5.2 | 15 x 35 | 17.9 |
| 3 | 2½-inch internal impinging jet | 11 | 100 | 30 | 105 | 6.0 | 210 | 5.7 | 15 x 35 | 17.5 |
| | | 12 | 200 | 30 | 130 | 7.0 | 260 | 5.4 | 15 x 40 | 19.7 |
| | | 13 | 300 | 30 | 155 | 9.5 | 310 | 6.1 | 15 x 40 | 19.2 |
| | | 14 | 400 | 30 | 185 | 9.7 | 370 | 5.3 | 20 x 60 | 18.7 |
| | | 15 | 500 | 30 | 200 | 10.0 | 400 | 5.0 | 20 x 60 | 17.1 |
| 4a | 2½-inch internal impinging jet with screen | 16 | 100 | 30 | 75 | 2.7 | 150 | 3.6 | 15 x 30 | 15.8 |
| | | 17 | 200 | 30 | 95 | 7.5 | 190 | 7.9 | 15 x 35 | 21.8 |
| | | 18 | 300 | 30 | 100 | 7.0 | 200 | 7.0 | 15 x 35 | 21.9 |
| | | 19 | 400 | 30 | 110 | 7.0 | 220 | 6.4 | 15 x 30 | 18.4 |
| | | 20 | 500 | 30 | 125 | 7.5 | 256 | 6.1 | 15 x 35 | 15.4 |
| 4b | 2½-inch internal impinging jet with stream shaper | 21 | 100 | 30 | 70 | 4.0 | 150 | 5.7 | 15 x 30 | 13.5 |
| | | 22 | 200 | 60 | 180 | 10.0 | 180 | 5.5 | 15 x 50 | 15.6 |
| | | 23 | 300 | 30 | 100 | 5.0 | 200 | 5.0 | 15 x 60 | 17.4 |
| | | 24 | 400 | 60 | 215 | 11.0 | 215 | 5.1 | 15 x 60 | 12.5 |
| | | 25 | 500 | 30 | 125 | 8.5 | 250 | 6.8 | 15 x 35 | 11.8 |
| 4c | 2½-inch internal impinging jet with screen | 26 | 100 | 60 | 110 | 7.0 | 110 | 6.2 | 15 x 30 | 23.2 |
| | | 27 | 200 | 60 | 145 | 8.5 | 145 | 5.8 | 15 x 30 | 19.1 |
| | | 28 | 300 | 60 | 180 | 9.0 | 180 | 5.0 | 15 x 45 | 30.4 |
| | | 29 | 400 | 60 | 210 | 10.0 | 210 | 4.7 | 15 x 45 | 19.7 |
| | | 30 | 500 | 60 | 240 | 12.0 | 240 | 5.0 | 20 x 35 | 21.9 |
| 4d | 2½-inch internal impinging jet with stream shaper | 31 | 100 | 60 | 115 | 7.0 | 115 | 6.0 | 15 x 60 | 12.4 |
| | | 32 | 200 | 60 | 145 | 8.0 | 145 | 5.5 | 15 x 35 | 17.4 |
| | | 33 | 300 | 30 | 90 | 6.0 | 180 | 6.7 | 15 x 70 | 12.5 |
| | | 34 | 400 | 30 | 110 | 7.0 | 220 | 6.3 | 15 x 70 | 10.3 |
| | | 35 | 500 | 60 | 245 | 12.0 | 245 | 4.9 | 20 x 65 | 11.4 |
| 5a | 2½-inch centrifugal with ½-inch orifice | 36 | 100 | 60 | 65 | 7.0 | 65 | 10.8 | 10 x 30 | 13.2 |
| | | 37 | 200 | 60 | 100 | 5.5 | 100 | 5.5 | 10 x 30 | 18.2 |
| | | 38 | 300 | 60 | 140 | 7.0 | 120 | 5.0 | 15 x 45 | 17.1 |
| | | 39 | 400 | 60 | 110 | 5.0 | 130 | 4.5 | 15 x 45 | 19.3 |
| | | 40 | 500 | 60 | 150 | 7.0 | 150 | 4.6 | 20 x 45 | 19.6 |
| 5b | 2½-inch centrifugal with 23/32-inch orifice | 41 | 100 | 60 | 135 | 5.0 | 135 | 3.7 | 15 x 40 | 18.4 |
| | | 42 | 200 | 60 | 150 | 7.0 | 150 | 4.6 | 20 x 40 | 17.2 |
| | | 43 | 300 | 60 | 180 | 7.0 | 180 | 3.9 | 20 x 40 | 19.0 |
| | | 44 | 400 | 60 | 210 | 9.0 | 210 | 4.2 | 20 x 45 | 20.0 |
| | | 45 | 500 | 60 | 250 | 8.0 | 250 | 3.3 | 20 x 45 | 17.4 |
| 6a | 2½-inch centrifugal with 1-inch orifice | 46 | 100 | 60 | 260 | 16.0 | 260 | 6.1 | 20 x 45 | 11.8 |
| | | 47 | 200 | 30 | 170 | 10.0 | 340 | 5.9 | 15 x 60 | 16.2 |
| | | 48 | 300 | 30 | 185 | 11.0 | 370 | 5.9 | 20 x 50 | 16.5 |
| | | 49 | 400 | 30 | 210 | 11.0 | 420 | 5.2 | 20 x 70 | 19.2 |
| | | 50 | 500 | - | - | - | - | - | - | - |
| 6b | 2½-inch centrifugal with 1¼-inch orifice | 51 | 100 | 60 | 360 | 22.0 | 360 | 6.1 | 20 x 50 | 13.9 |
| | | 52 | 200 | 30 | 190 | 11.0 | 380 | 5.8 | 20 x 60 | 17.5 |
| | | 53 | 300 | 30 | 235 | 13.7 | 470 | 5.8 | 20 x 60 | 17.0 |
| | | 54 | 400 | - | - | - | - | - | - | - |
| | | 55 | 500 | - | - | - | - | - | - | - |
| 7a | 2½-inch centrifugal with 1½-inch orifice | 56 | 100 | 60 | 490 | 28.0 | 490 | 5.7 | 20 x 35 | 11.7 |
| | | 57 | 200 | 30 | 245 | 12.0 | 490 | 4.9 | 20 x 35 | 10.7 |
| | | 58 | 300 | - | - | - | - | - | - | - |
| | | 59 | 400 | - | - | - | - | - | - | - |
| | | 60 | 500 | - | - | - | - | - | - | - |
| 7b | 2½-inch centrifugal with 1 3/4-inch orifice | 61 | 100 | 30 | 215 | 13.1 | 430 | 6.1 | 15 x 45 | 8.0 |
| | | 62 | 200 | 30 | 250 | 12.0 | 500 | 4.8 | 15 x 45 | 9.5 |
| | | 63 | 300 | - | - | - | - | - | - | - |
| | | 64 | 400 | - | - | - | - | - | - | - |
| | | 65 | 500 | - | - | - | - | - | - | - |
| 8 | 2½-inch German adjustable hollow cone | 66 | 100 | 120 | 30 | premix | 15 | 6.0 | 15 x 15 | 13.7 |
| | | 67 | 200 | 120 | 48 | premix | 24 | 6.0 | 20 x 15 | 15.0 |
| | | 68 | 300 | 120 | 54 | premix | 27 | 6.0 | 15 x 10 | 20.8 |
| | | 69 | 400 | 120 | 58 | premix | 29 | 6.0 | 10 x 10 | 18.8 |
| | | 70 | 500 | - | - | - | - | - | - | - |
| 9 | 1½-inch external impinging jet | 71 | 100 | 60 | 100 | 6.0 | 100 | 6.0 | 15 x 30 | 13.8 |
| | | 72 | 200 | 60 | 130 | 8.0 | 130 | 6.1 | 15 x 30 | 18.2 |
| | | 73 | 300 | 60 | 160 | 7.0 | 160 | 4.3 | 15 x 30 | 19.1 |
| | | 74 | 400 | 60 | 185 | 9.4 | 185 | 5.1 | 15 x 30 | 16.0 |

## Table II. Comparison of Field Test Results.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| Nozzle No. | Nozzle Type | Run No. | Nozzle Pressure (psi) | Theoretical Foam Production Rate (gpm) | Actual Foam Production Rate (gpm) | Foam Yield (%) | Foam Expansion Ratio |
| 1 | 2½-inch external impinging jet | 1 | 100 | 1060 | 224 | 21 | 10.7 |
| | | 2 | 200 | 974 | 382 | 40 | 8.1 |
| | | 3 | 300 | 1071 | 457 | 43 | 6.9 |
| | | 4 | 400 | 1221 | 457 | 37 | 6.8 |
| | | 5 | 500 | 1297 | 326 | 43 | 6.2 |
| 2 | 2½-inch external impinging jet with fan-shaped diffuser | 6 | 100 | 1241 | 172 | 14 | 10.4 |
| | | 7 | 200 | 1650 | 300 | 18 | 10.4 |
| | | 8 | 300 | 1312 | 195 | 15 | 7.7 |
| | | 9 | 400 | 1178 | 195 | 17 | 5.9 |
| | | 10 | 500 | 1900 | 174 | 12 | 7.1 |
| 3 | 2½-inch internal impinging jet | 11 | 100 | 2019 | 615 | 30 | 9.8 |
| | | 12 | 200 | 2130 | 600 | 28 | 8.2 |
| | | 13 | 300 | 2209 | 607 | 27 | 7.1 |
| | | 14 | 400 | 2400 | 742 | 31 | 6.5 |
| | | 15 | 500 | 2880 | 885 | 30 | 7.2 |
| 4a | 2½-inch internal impinging jet with screen | 16 | 100 | 1335 | 390 | 29 | 8.9 |
| | | 17 | 200 | 1105 | 690 | 62 | 5.8 |
| | | 18 | 300 | 1140 | 600 | 53 | 5.6 |
| | | 19 | 400 | 1365 | 705 | 51 | 6.2 |
| | | 20 | 500 | 1860 | 675 | 36 | 7.2 |
| 4b | 2½-inch internal impinging jet with stream shaper | 21 | 100 | 1500 | 712 | 48 | 10.1 |
| | | 22 | 200 | 1672 | 1072 | 65 | 9.3 |
| | | 23 | 300 | 1320 | 712 | 54 | 6.6 |
| | | 24 | 400 | 1875 | 1005 | 53 | 8.7 |
| | | 25 | 500 | 1800 | 788 | 44 | 7.1 |
| 4c | 2½-inch internal impinging jet with screen | 26 | 100 | 690 | 270 | 39 | 6.3 |
| | | 27 | 200 | 915 | 419 | 46 | 6.3 |
| | | 28 | 300 | 1221 | 525 | 43 | 6.8 |
| | | 29 | 400 | 1335 | 565 | 42 | 6.4 |
| | | 30 | 500 | 1365 | 585 | 43 | 5.7 |
| 4d | 2½-inch internal impinging jet with stream shaper | 31 | 100 | 1230 | 690 | 56 | 10.7 |
| | | 32 | 200 | 1102 | 735 | 66 | 7.6 |
| | | 33 | 300 | 1500 | 900 | 60 | 8.3 |
| | | 34 | 400 | 1560 | 900 | 58 | 7.6 |
| | | 35 | 500 | 1671 | 936 | 57 | 6.7 |
| 5a | 2½-inch centrifugal with ½-inch orifice | 36 | 100 | 633 | 75 | 12 | 10.1 |
| | | 37 | 200 | 945 | 145 | 15 | 9.5 |
| | | 38 | 300 | 900 | 214 | 24 | 7.5 |
| | | 39 | 400 | 1050 | 228 | 22 | 8.1 |
| | | 40 | 500 | 1125 | 252 | 20 | 7.5 |
| 5b | 2½-inch centrifugal with 23/32-inch orifice | 41 | 100 | 1307 | 195 | 14 | 10.1 |
| | | 42 | 200 | 1500 | 368 | 25 | 10.3 |
| | | 43 | 300 | 1541 | 420 | 27 | 8.5 |
| | | 44 | 400 | 1410 | 360 | 25 | 6.7 |
| | | 45 | 500 | 1461 | 338 | 23 | 6.3 |
| 6a | 2½-inch centrifugal with 1-inch orifice | 46 | 100 | 2590 | 660 | 25 | 10.5 |
| | | 47 | 200 | 3300 | 900 | 27 | 9.8 |
| | | 48 | 300 | 2820 | 975 | 35 | 7.6 |
| | | 49 | 400 | 3450 | 1015 | 30 | 8.1 |
| | | 50 | 500 | - | - | - | - |
| 6b | 2½-inch centrifugal with 1¼-inch orifice | 51 | 100 | 3600 | 825 | 23 | 10.2 |
| | | 52 | 200 | 3850 | 1275 | 33 | 10.2 |
| | | 53 | 300 | 3600 | 1950 | 55 | 8.1 |
| | | 54 | 400 | - | - | - | - |
| | | 55 | 500 | - | - | - | - |
| 7a | 2½-inch centrifugal with 1½-inch orifice | 56 | 100 | 6218 | 1350 | 22 | 12.5 |
| | | 57 | 200 | 4950 | 1425 | 29 | 10.2 |
| | | 58 | 300 | - | - | - | - |
| | | 59 | 400 | - | - | - | - |
| | | 60 | 500 | - | - | - | - |
| 7b | 2½-inch centrifugal with 1 3/4-inch orifice | 61 | 100 | 5890 | 1275 | 22 | 13.7 |
| | | 62 | 200 | 6220 | 1390 | 23 | 12.5 |
| | | 63 | 300 | - | - | - | - |
| | | 64 | 400 | - | - | - | - |
| | | 65 | 500 | - | - | - | - |
| 8 | 2½-inch German adjustable hollow cone | 66 | 100 | 275 | 30 | 12 | 10.3 |
| | | 67 | 200 | 188 | 38 | 20 | 7.8 |
| | | 68 | 300 | 270 | 22 | 8 | 10.8 |
| | | 69 | 400 | 210 | 11 | 5 | 7.5 |
| | | 70 | 500 | - | - | - | - |
| 9 | 1½-inch external impinging jet | 71 | 100 | 1110 | 375 | 34 | 11.1 |
| | | 72 | 200 | 1065 | 412 | 39 | 8.2 |
| | | 73 | 300 | 907 | 195 | 22 | 5.7 |
| | | 74 | 400 | 1310 | 375 | 25 | 8.2 |

A

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 53 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | | 54 | 400 | - | - | - | - | - | - | - |
| | | 55 | 500 | - | - | - | - | - | - | - |
| 7a | 2½-inch centrifugal with 1½-inch orifice | 56 | 100 | 60 | 490 | 28.0 | 470 | 5.7 | 20 x 55 | 11.7 |
| | | 57 | 200 | 30 | 245 | 12.0 | 490 | 4.9 | 20 x 55 | 10.7 |
| | | 58 | 300 | - | - | - | - | - | - | - |
| | | 59 | 400 | - | - | - | - | - | - | - |
| | | 60 | 500 | - | - | - | - | - | - | - |
| 7b | 2½-inch centrifugal with 1 3/4-inch orifice | 61 | 100 | 30 | 215 | 13.0 | 430 | 6.1 | 15 x 45 | 8.0 |
| | | 62 | 200 | 30 | 250 | 12.0 | 500 | 4.8 | 15 x 45 | 9.5 |
| | | 63 | 300 | - | - | - | - | - | - | - |
| | | 64 | 400 | - | - | - | - | - | - | - |
| | | 65 | 500 | - | - | - | - | - | - | - |
| 8 | 2½-inch German adjustable hollow cone | 66 | 100 | 120 | 30 | premix | 15 | 6.0 | 15 x 15 | 13.7 |
| | | 67 | 200 | 120 | 48 | premix | 24 | 6.0 | 20 x 15 | 15.0 |
| | | 68 | 300 | 120 | 54 | premix | 27 | 6.0 | 15 x 10 | 20.8 |
| | | 69 | 400 | 120 | 58 | premix | 29 | 6.0 | 10 x 10 | 18.8 |
| | | 70 | 500 | - | - | - | - | - | - | - |
| 9 | 1½-inch external impinging jet | 71 | 100 | 60 | 100 | 6.0 | 100 | 6.0 | 15 x 30 | 15.2 |
| | | 72 | 200 | 60 | 130 | 8.0 | 130 | 6.1 | 15 x 30 | 18.2 |
| | | 73 | 300 | 60 | 160 | 7.0 | 160 | 4.3 | 15 x 30 | 19.1 |
| | | 74 | 400 | 60 | 185 | 9.4 | 185 | 5.1 | 15 x 30 | 16.0 |
| | | 75 | 500 | - | - | - | - | - | - | - |
| 10a | 1½-inch internal impinging jet with screen | 76 | 100 | 60 | 12 | premixed | 12 | 6.0 | 10 x 15 | 15.2 |
| | | 77 | 200 | 60 | 23 | do | 23 | 6.0 | 10 x 15 | 13.4 |
| | | 78 | 300 | 60 | 27 | do | 27 | 6.0 | 10 x 15 | 16.5 |
| | | 79 | 400 | 60 | 28 | do | 28 | 6.0 | 20 x 20 | 15.5 |
| | | 80 | 500 | 60 | 39 | do | 39 | 6.0 | 15 x 40 | 14.0 |
| 10b | 1½-inch internal impinging jet with screen | 81 | 100 | 60 | 20 | do | 20 | 6.0 | 10 x 20 | 17.9 |
| | | 82 | 200 | 60 | 24 | do | 24 | 6.0 | 10 x 30 | 18.5 |
| | | 83 | 300 | 120 | 54 | do | 27 | 6.0 | 10 x 20 | 17.6 |
| | | 84 | 400 | 120 | 64 | do | 32 | 6.0 | 20 x 20 | 15.2 |
| | | 85 | 500 | 60 | 37 | do | 37 | 6.0 | 20 x 20 | 15.5 |
| 10c | 1½-inch internal impinging jet with screen | 86 | 100 | 60 | 32 | do | 32 | 6.0 | 10 x 15 | 15.4 |
| | | 87 | 200 | 60 | 33 | do | 33 | 6.0 | 20 x 20 | 18.8 |
| | | 88 | 300 | 60 | 38 | do | 38 | 6.0 | 20 x 20 | 19.4 |
| | | 89 | 400 | 60 | 40 | do | 40 | 6.0 | 20 x 15 | 14.8 |
| | | 90 | 500 | 60 | 55 | do | 55 | 6.0 | 20 x 15 | 13.0 |
| 11a | 1½-inch internal impinging jet with screen, bumper type | 91 | 100 | 60 | 70 | 4.5 | 70 | 6.4 | 15 x 15 | 12.0 |
| | | 92 | 200 | 60 | 95 | 7.5 | 95 | 7.9 | 25 x 20 | 9.4 |
| | | 93 | 300 | 60 | 120 | 8.0 | 120 | 6.7 | 20 x 20 | 12.7 |
| | | 94 | 400 | 60 | 150 | 9.5 | 150 | 6.3 | 15 x 45 | 14.7 |
| | | 95 | 500 | 60 | 160 | 10.5 | 160 | 6.6 | 15 x 55 | 17.4 |
| 11b | 1½-inch internal impinging jet with screen, bumper type | 96 | 100 | 15 | 25 | premixed | 100 | 6.0 | 20 x 30 | 19.7 |
| | | 97 | 200 | 60 | 120 | do | 120 | 6.0 | 20 x 35 | 20.4 |
| | | 98 | 300 | 30 | 70 | do | 140 | 6.0 | 20 x 30 | 20.7 |
| | | 99 | 400 | 60 | 175 | do | 175 | 6.0 | 20 x 35 | 12.7 |
| | | 100 | 500 | 60 | 200 | do | 200 | 6.0 | 20 x 35 | 11.5 |
| 12 | 2½-inch straight stream aspirating foam nozzle with fan-shaped diffusor | 101 | 100 | 30 | 55 | 5.0 | 110 | 5.5 | 15 x 30 | 15.5 |
| | | 102 | 200 | 30 | 90 | 5.0 | 180 | 5.5 | 15 x 45 | 4.2 |
| | | 103 | 300 | 30 | 105 | 6.0 | 210 | 5.7 | 15 x 45 | 1.9 |
| | | 104 | 400 | 60 | 240 | 18.0 | 240 | 7.5 | 15 x 70 | 9.0 |
| | | 105 | 500 | 30 | 130 | 6.0 | 260 | 4.6 | 15 x 60 | 21.5 |
| 13 | 2½-inch straight stream aspirating foam nozzle with fan-shaped diffusor | 106 | 100 | 30 | 85 | 5.5 | 170 | 4.1 | 10 x 50 | 17.7 |
| | | 107 | 200 | 60 | 218 | 12.0 | 218 | 5.5 | 15 x 65 | 15.2 |
| | | 108 | 300 | 60 | 250 | 15.5 | 250 | 6.2 | 20 x 70 | 13.4 |
| | | 109 | 400 | 60 | 290 | 16.5 | 290 | 5.7 | 20 x 75 | 10.4 |
| | | 110 | 500 | 30 | 155 | 8.0 | 310 | 5.2 | 15 x 75 | 14.9 |
| 14 | 2½-inch external impinging jet | 111 | 100 | 30 | 230 | 13.0 | 460 | 5.6 | 15 x 55 | 15.7 |
| | | 112 | 200 | 30 | 235 | 13.5 | 470 | 5.7 | 15 x 50 | 12.4 |
| | | 113 | 300 | - | - | - | - | - | - | - |
| | | 114 | 400 | - | - | - | - | - | - | - |
| | | 115 | 500 | - | - | - | - | - | - | - |
| 15 | 2½-inch adjustable hollow cone | 116 | 100 | 60 | 165 | 7.0 | 165 | 4.2 | 15 x 45 | 11.0 |
| | | 117 | 200 | 60 | 190 | 10.0 | 190 | 5.3 | 20 x 45 | 13.7 |
| | | 118 | 300 | 60 | 240 | 13.0 | 240 | 5.4 | 15 x 75 | 16.5 |
| | | 119 | 400 | 60 | 260 | 20.0 | 260 | 7.7 | 15 x 75 | 17.4 |
| | | 120 | 500 | 60 | 290 | 16.0 | 290 | 5.5 | 20 x 60 | 17.0 |
| 16 | 2½-inch adjustable hollow cone with aspirator | 121 | 100 | 30 | 60 | 5.5 | 120 | 5.8 | 12 x 15 | 12.9 |
| | | 122 | 200 | 30 | 80 | 5.0 | 160 | 6.2 | 15 x 40 | 9.4 |
| | | 123 | 300 | 30 | 107 | 6.0 | 214 | 5.6 | 15 x 40 | 14.3 |
| | | 124 | 400 | 30 | 113 | 6.0 | 226 | 5.3 | 20 x 35 | 22.2 |
| | | 125 | 500 | 30 | 140 | 8.0 | 240 | 5.7 | 15 x 40 | 8.5 |
| 17 | 1½-inch adjustable hollow cone | 126 | 100 | 60 | 125 | 6.5 | 125 | 5.2 | 25 x 20 | 14.7 |
| | | 127 | 200 | 60 | 150 | 9.0 | 150 | 6.0 | 15 x 45 | 19.0 |
| | | 128 | 300 | 60 | 170 | 10.5 | 170 | 6.2 | 20 x 40 | 18.0 |
| | | 129 | 400 | 60 | 190 | 11.0 | 190 | 5.8 | 20 x 40 | 16.7 |
| | | 130 | 500 | 60 | 210 | 14.0 | 210 | 6.7 | 15 x 50 | 18.3 |
| 18 | 2½-inch adjustable hollow cone | 131 | 100 | 60 | 200 | 12.0 | 200 | 6.0 | 25 x 55 | 13.9 |
| | | 132 | 200 | 60 | 210 | 12.0 | 210 | 5.7 | 15 x 65 | 12.2 |
| | | 133 | 300 | 60 | 290 | 19.0 | 290 | 6.5 | 35 x 60 | 14.7 |
| | | 134 | 400 | 30 | 155 | 7.0 | 310 | 4.5 | 25 x 45 | 18.7 |
| | | 135 | 500 | 30 | 165 | 10.0 | 330 | 6.1 | 30 x 40 | 19.8 |
| 19 | 2½-inch fan-shaped external impinging with diffusing orifices | 136 | 100 | 60 | 240 | 15.0 | 240 | 6.2 | 30 x 30 | 14.2 |
| | | 137 | 200 | 30 | 150 | 9.0 | 300 | 6.0 | 30 x 35 | 17.0 |
| | | 138 | 300 | 30 | 170 | 11.0 | 340 | 6.5 | 35 x 30 | 14.5 |
| | | 139 | 350 Max 400 | 30 | 180 | 12.0 | 360 | 6.6 | 30 x 45 | 17.5 |
| | | 140 | 500 | - | - | - | - | - | - | - |
| 20 | 2½-inch internal impinging jet | 141 | 80 Max 100 | 30 | 250 | 15 | 500 | 6 | 30 x 35 | 5.5 |
| | | 142 | 200 | - | - | -- | - | - | - | - |
| | | 143 | 300 | - | - | - | - | - | - | - |
| | | 144 | 400 | - | - | - | - | - | - | - |
| | | 145 | 500 | - | - | - | - | - | - | - |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 53 | [illegible] | [illegible] | [illegible] | | [illegible] |
| | | 54 | 400 | - | - | - | - |
| | | 55 | 500 | - | - | - | - |
| 7a | 2½-inch centrifugal with 1½-inch orifice | 56 | 100 | 6210 | 1350 | 22 | 12.5 |
| | | 57 | 200 | 4950 | 1425 | 29 | 10.2 |
| | | 58 | 300 | - | - | - | - |
| | | 59 | 400 | - | - | - | - |
| | | 60 | 500 | - | - | - | - |
| 7b | 2½-inch centrifugal with 1 3/4-inch orifice | 61 | 100 | 5890 | 1275 | 22 | 13.7 |
| | | 62 | 200 | 6220 | 1390 | 23 | 12.5 |
| | | 63 | 300 | - | - | - | - |
| | | 64 | 400 | - | - | - | - |
| | | 65 | 500 | - | - | - | - |
| 8 | 2½-inch German adjustable hollow cone | 66 | 100 | 255 | 30 | 12 | 10.3 |
| | | 67 | 200 | 188 | 38 | 20 | 7.8 |
| | | 68 | 300 | 292 | 22 | 8 | 10.8 |
| | | 69 | 400 | 210 | 11 | 5 | 7.3 |
| | | 70 | 500 | - | - | - | - |
| 9 | 1½-inch external impinging jet | 71 | 100 | 1110 | 375 | 34 | 11.1 |
| | | 72 | 200 | 1065 | 412 | 39 | 8.2 |
| | | 73 | 300 | 907 | 195 | 22 | 5.7 |
| | | 74 | 400 | 1510 | 375 | 25 | 8.2 |
| | | 75 | 500 | - | - | - | - |
| 10a | 1½-inch internal impinging jet with screen | 76 | 100 | 113 | 38 | 33 | 9.5 |
| | | 77 | 200 | 187 | 90 | 48 | 7.6 |
| | | 78 | 300 | 157 | 75 | 47 | 5.9 |
| | | 79 | 400 | 150 | 83 | 55 | 5.4 |
| | | 80 | 500 | 202 | 90 | 45 | 5.2 |
| 10b | 1½-inch internal impinging jet with screen | 81 | 100 | 157 | 53 | 33 | 7.7 |
| | | 82 | 200 | 165 | 90 | 55 | 6.9 |
| | | 83 | 300 | 187 | 98 | 52 | 6.8 |
| | | 84 | 400 | 195 | 98 | 50 | 6.1 |
| | | 85 | 500 | 270 | 60 | 22 | 7.4 |
| 10c | 1½-inch internal impinging jet with screen | 86 | 100 | 285 | 60 | 21 | 9.1 |
| | | 87 | 200 | 255 | 98 | 38 | 7.2 |
| | | 88 | 300 | 278 | 98 | 35 | 7.4 |
| | | 89 | 400 | 262 | 105 | 40 | 6.6 |
| | | 90 | 500 | 300 | 98 | 33 | 5.4 |
| 11a | 1½-inch internal impinging jet with screen, bumper type | 91 | 100 | 675 | 278 | 41 | 9.6 |
| | | 92 | 200 | 900 | 435 | 48 | 9.5 |
| | | 93 | 300 | 795 | 330 | 42 | 6.6 |
| | | 94 | 400 | 915 | 398 | 44 | 6.1 |
| | | 95 | 500 | 990 | 413 | 42 | 6.2 |
| 11b | 1½-inch internal impinging jet with screen, bumper type | 96 | 100 | 878 | 450 | 51 | 8.8 |
| | | 97 | 200 | 885 | 513 | 58 | 7.4 |
| | | 98 | 300 | 1162 | 525 | 45 | 8.3 |
| | | 99 | 400 | 1260 | 532 | 42 | 7.2 |
| | | 100 | 500 | 1185 | 443 | 37 | 5.8 |
| 12 | 2½-inch straight stream aspirating foam nozzle with fan-shaped difusor | 101 | 100 | 1372 | 472 | 34 | 9.8 |
| | | 102 | 200 | 1725 | 1089 | 63 | 9.3 |
| | | 103 | 300 | 1990 | 1275 | 64 | 9.4 |
| | | 104 | 400 | 2180 | 1350 | 62 | 9.3 |
| | | 105 | 500 | 1761 | 975 | 55 | 6.5 |
| 13 | 2½-inch straight stream aspirating foam nozzle with fan-shaped difusor | 106 | 100 | 1680 | 975 | 58 | 9.9 |
| | | 107 | 200 | 1785 | 1275 | 72 | 8.2 |
| | | 108 | 300 | 1850 | 1350 | 73 | 7.3 |
| | | 109 | 400 | 2032 | 1425 | 70 | 7.2 |
| | | 110 | 500 | 2298 | 1461 | 64 | 7.4 |
| 14 | 2½-inch external impinging jet | 111 | 100 | 5480 | 3221 | 60 | 11.7 |
| | | 112 | 200 | 5960 | 3718 | 62 | 12.7 |
| | | 113 | 300 | - | - | - | - |
| | | 114 | 400 | - | - | -- | - |
| | | 115 | 500 | - | - | - | - |
| 15 | 2½-inch adjustable hollow cone | 116 | 100 | 1650 | 300 | 18 | 10.6 |
| | | 117 | 200 | 1905 | 465 | 24 | 10.2 |
| | | 118 | 300 | 2238 | 518 | 23 | 9.3 |
| | | 119 | 400 | 2180 | 714 | 33 | 8.3 |
| | | 120 | 500 | 2350 | 505 | 21 | 6.1 |
| 16 | 2½-inch adjustable hollow cone with aspirator | 121 | 100 | 924 | 450 | 49 | 7.7 |
| | | 122 | 200 | 1140 | 525 | 46 | 7.1 |
| | | 123 | 300 | 1329 | 636 | 48 | 6.2 |
| | | 124 | 400 | 1400 | 630 | 45 | 6.2 |
| | | 125 | 500 | 1878 | 660 | 35 | 7.8 |
| 17 | 1½-inch adjustable hollow cone | 126 | 100 | 1140 | 232 | 20 | 9.2 |
| | | 127 | 200 | 1161 | 428 | 38 | 7.7 |
| | | 128 | 300 | 1221 | 457 | 37 | 7.2 |
| | | 129 | 400 | 1275 | 390 | 30 | 6.7 |
| | | 130 | 500 | 1333 | 285 | 21 | 6.4 |
| 18 | 2½-inch adjustable hollow cone | 131 | 100 | 2021 | 517 | 26 | 10.1 |
| | | 132 | 200 | 2121 | 712 | 34 | 10.3 |
| | | 133 | 300 | 2180 | 900 | 42 | 7.4 |
| | | 134 | 400 | 1989 | 600 | 30 | 6.4 |
| | | 135 | 500 | 2400 | 709 | 29 | 6.3 |
| 19 | 2½-inch fan-shaped external impinging with difusing orifices | 136 | 100 | 2562 | 1208 | 47 | 10.7 |
| | | 137 | 200 | 2815 | 1485 | 53 | 9.4 |
| | | 138 | 300 | 2601 | 1200 | 45 | 7.8 |
| | | 139 | 350 Max 400 | 3039 | 1500 | 49 | 8.[illegible] |
| | | 140 | 500 | - | - | - | - |
| 20 | 2½-inch internal impinging jet | 141 | 80 Max 100 | 6295 | 2250 | 37 | 1[illegible].6 |
| | | 142 | 200 | - | - | - | - |
| | | 143 | 300 | - | - | - | - |
| | | 144 | 400 | - | - | - | - |
| | | 145 | 500 | - | - | -- | - |



B

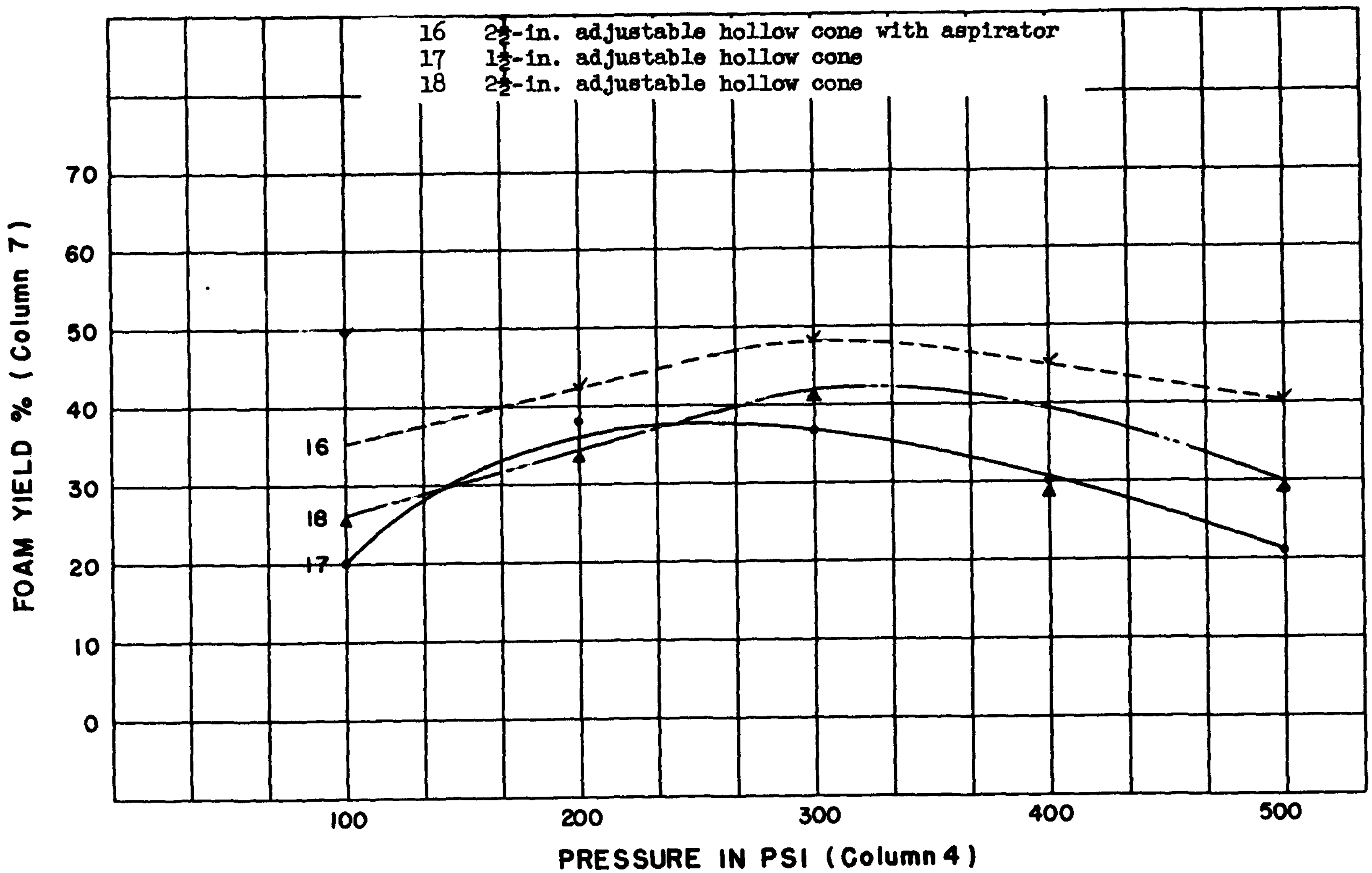



Fig. 14. Foam yield vs. nozzle pressure (Table II) for nozzles 16, 17, and 18.

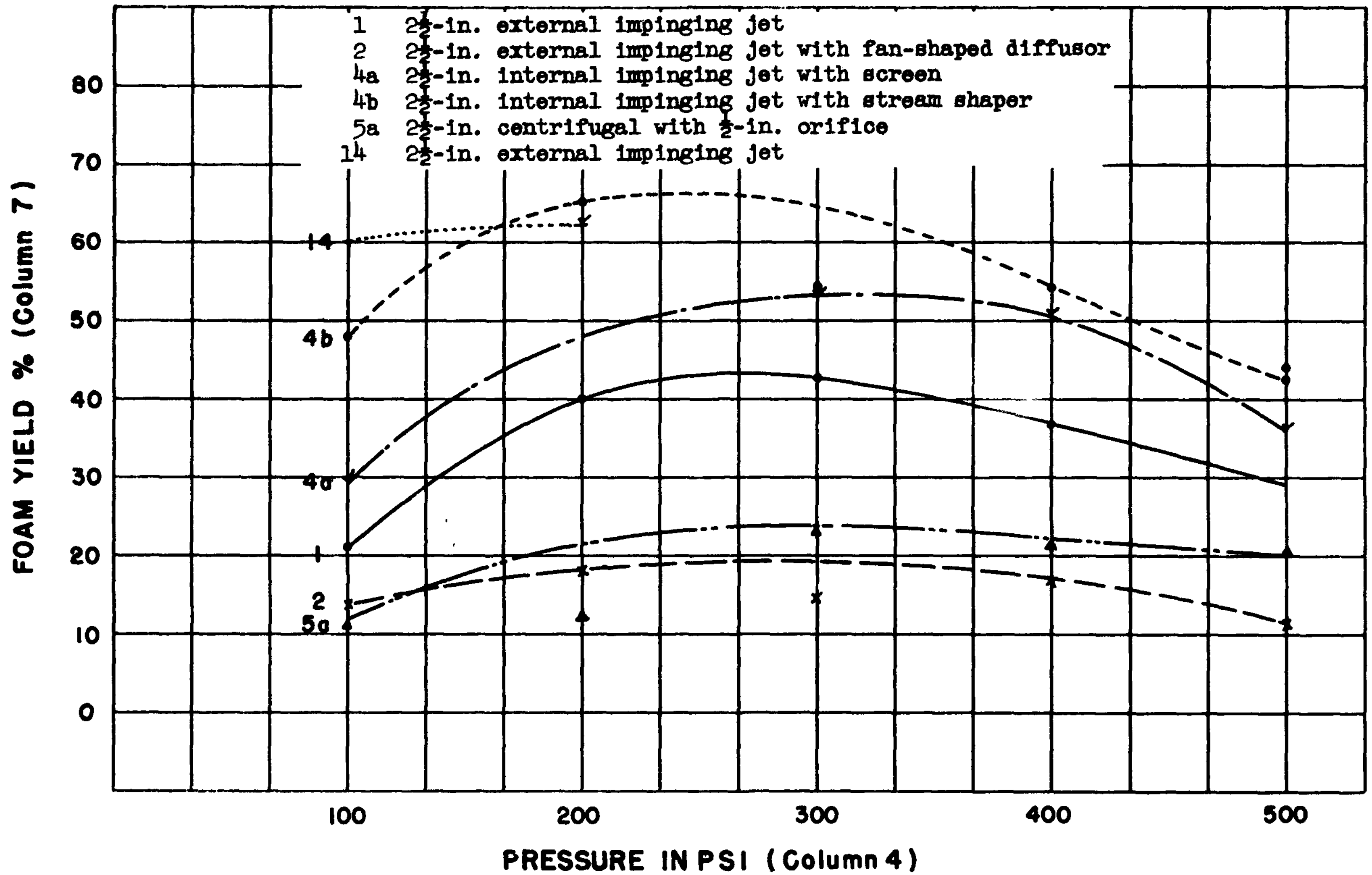



Fig. 15. Foam yield vs. nozzle pressure (Table II) for nozzles 1, 2, 4a and b, 5a, and 14.

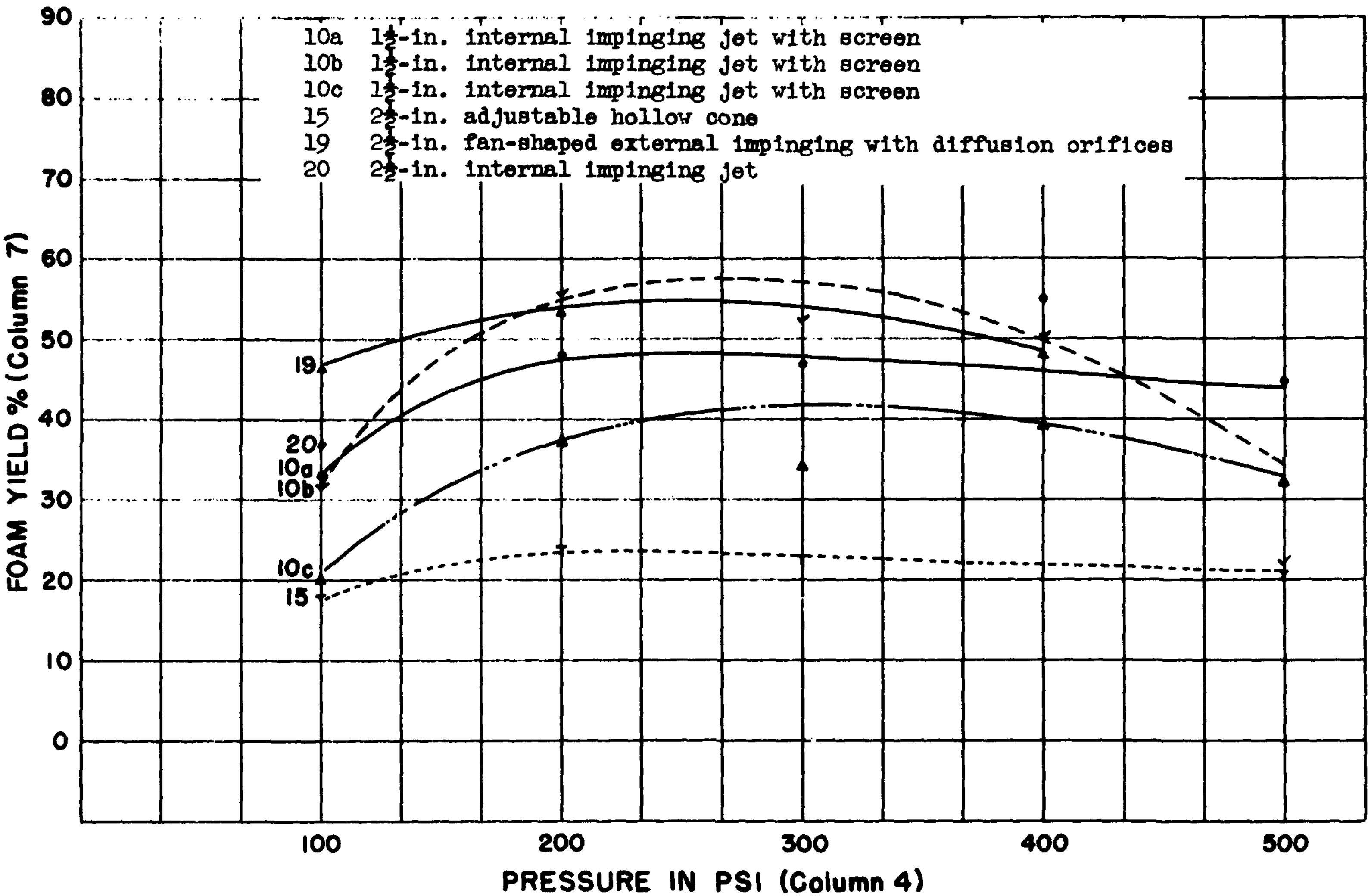



Fig. 16. Foam yield vs. nozzle pressure (Table II) for nozzles 10a, b, and c, 15, 19, and 20. Because of the limitations of test equipment only one reading was possible for nozzle 20.

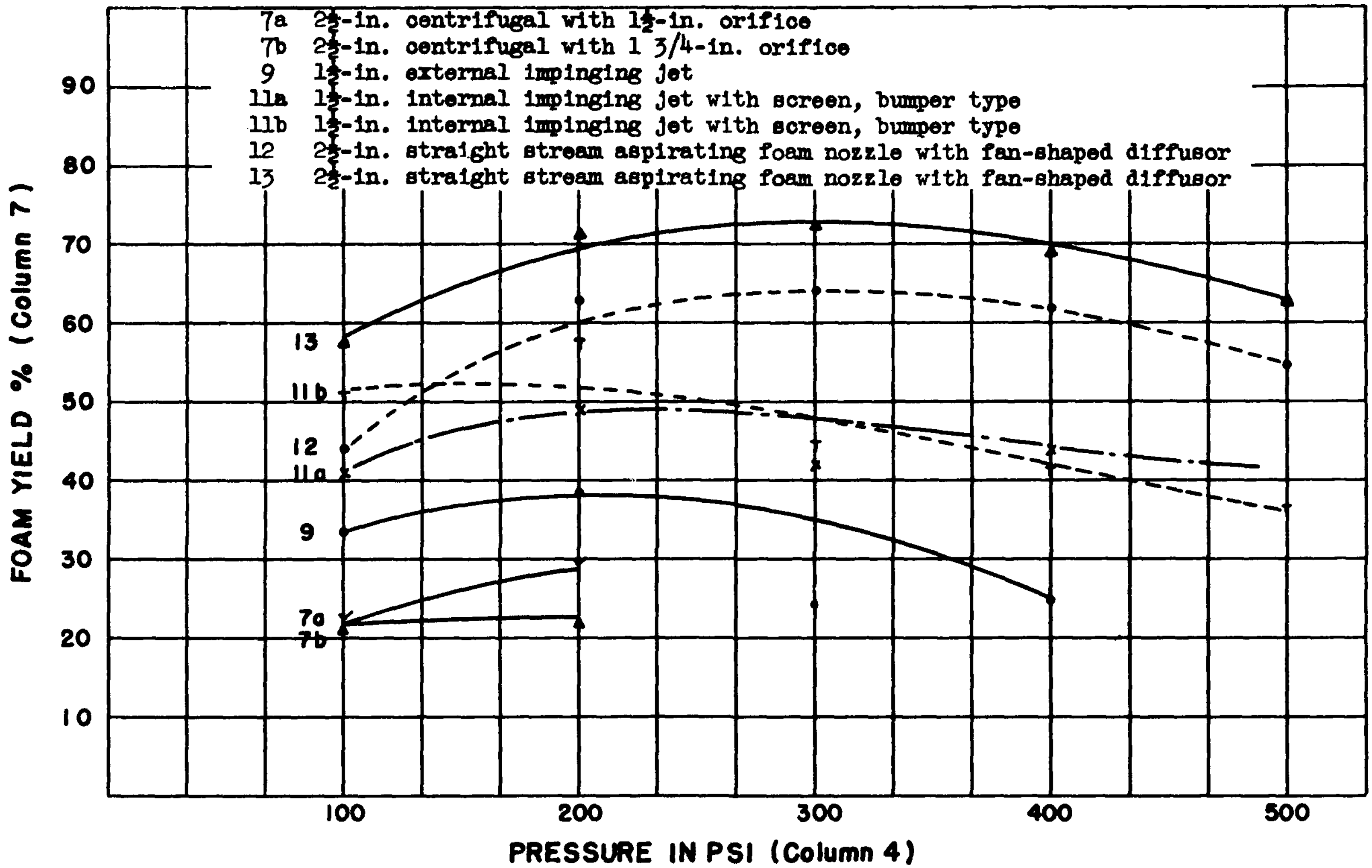



Fig. 17. Foam yield vs. nozzle pressure (Table II) for nozzles 7a and b, 9, 11a and b, 12, and 13.

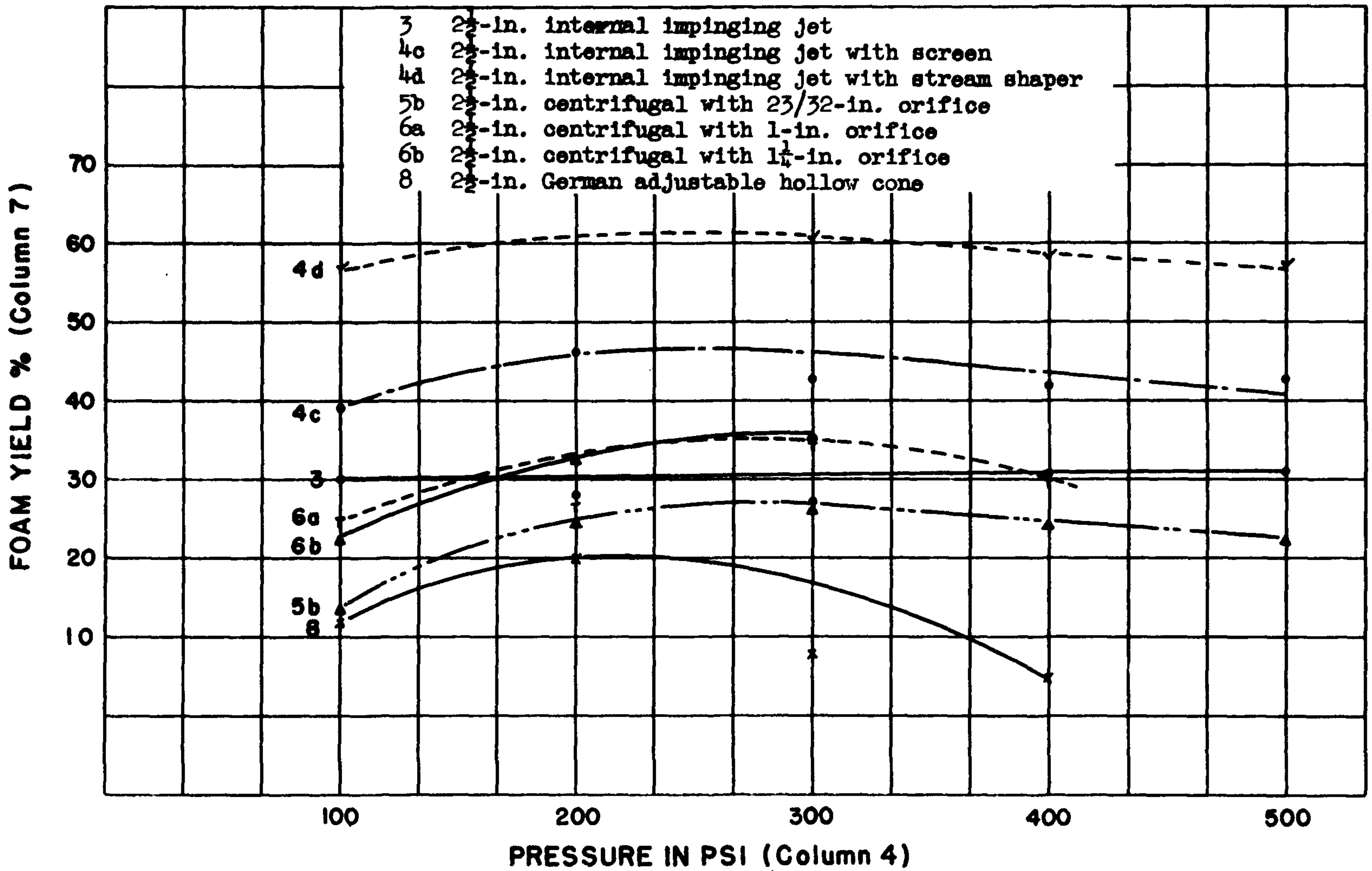



Fig. 18. Foam yield vs. nozzle pressure (Table II) for nozzles 3, 4c and d, 5b, 6a and b, and 8.

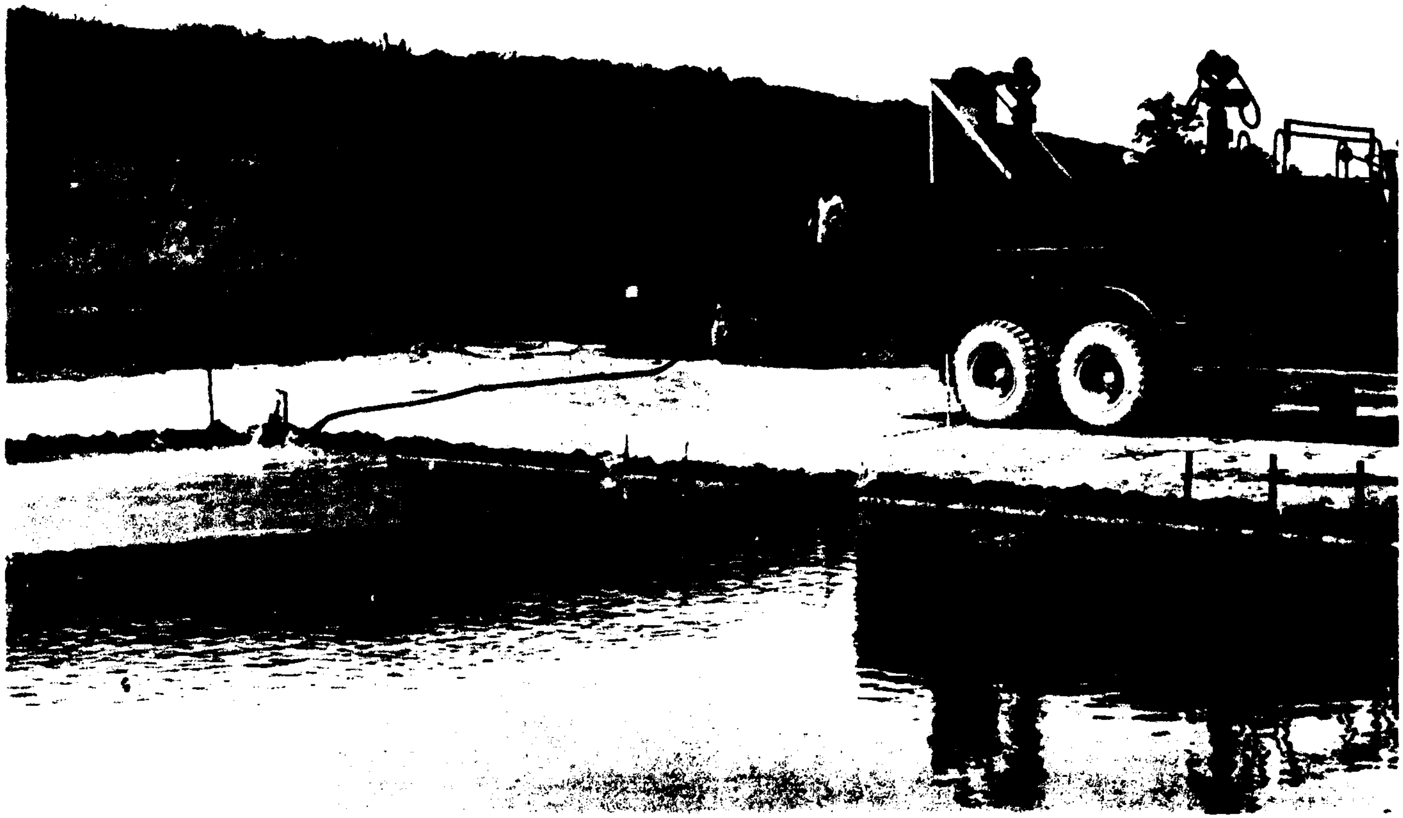
184-3-759

Fig. 19. In fire test area, pools were laid out so as to permit downwind approach to fire from more than one side.

b. Conditions. Two adjacent 25- by 50-foot burning pools (Fig. 20) were constructed on a concrete slab by setting up steel beams and covering them with sandy clay and gravel to make the pool water tight. These were partly filled with water in order to obtain a perfectly level surface. The wind, temperature, and humidity were recorded. During the fire tests the wind velocity had a more critical effect than it did during the screening tests; therefore, no tests were run under windy (over 4 mph) or rainy conditions.

c. Procedure. Industrial naphtha totaling 375 gallons was added to a pool and ignited. Foam was applied after a 5 seconds preburn and the data were recorded in Table III. One observer recorded all the data. The pools were filled as shown in Figs. 20 and 21. Clear unleaded gasoline, with zero octane rating, commercially known as industrial naphtha, was used throughout the fire tests.

All nozzles were used from the turret of the Class 155 crash fire truck, and locked in place with the nozzle extension depressed approximately 10 degrees from the horizontal. (Depressing the nozzle over 10 degrees at the higher pressures caused the fuel to splatter and burn over the edge of the pool as shown in Fig. 22). The Class 155 crash fire truck was parked so that



184-3-692

Fig. 20. Two test pools of identical area were laid out adjacent to one another on large concrete slab. Each was filled with water to insure perfectly level surface and to prevent cracking of concrete base. Class 155 crash fire truck was parked at right angles to longer axis of pit.

# Table III. Fire Test Field Data

| 1<br>Nozzle No. | 2<br>Nozzle Type | 3<br>Nozzle Pressure (psi) | 4<br>Control Time (sec) | 5<br>Est. % Extin-guishment | 6<br>Est. Foam Depth (in.) | 7<br>Wind Vel. (mph) | 8<br>Wind Direction | 9<br>Nozzle Distance fr Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2½-inch external impinging jet | 100 | * | * | * | * | * | * |
| | | 200 | Infinity | 10 | - | 2 | 3 | 8 |
| | | 200 | do | 10 | - | 2 | 3 | 8 |
| | | 300 | do | 50 | - | 2 | 3 | 10 |
| | | 300 | do | 30 | - | 2 | 3 | 10 |
| | | 400 | do | 65 | - | 3 | 3 | 10 |
| | | 400 | do | 10 | - | 2 | 3 | 10 |
| | | 400 | do | 10 | - | 2 | 3 | 10 |
| | | 500 | do | 65 | - | 3 | 3 | 15 |
| | | 500 | do | 10 | - | 3 | 3 | 15 |
| | | 500 | do | 10 | - | 2 | 3 | 15 |
| 3 | 2½-inch internal impinging jet | 100 | No runs were conducted at this pressure. | | | | | |
| | | 200 | 30 | 90 | 1/2 | 4 | 9 | 8 |
| | | 200 | 80 | 90 | 1/2 | 4 | 9 | 8 |
| | | 200 | 105 | 90 | 1/2 | 4 | 3 | 8 |
| | | 300 | 75 | 90 | 1/2 | 4 | 9 | 8 |
| | | 300 | 95 | 90 | 1 | 4 | 9 | 8 |
| | | 300 | 58 | 90 | 1 | 4 | 3 | 8 |
| | | 400 | 50 | 90 | 1/2 | 4 | 9 | 8 |
| | | 400 | 43 | 90 | 1 1/2 | 4 | 9 | 8 |
| | | 400 | 50 | 90 | 1 | 4 | 3 | 8 |
| | | 500 | * | * | * | * | * | * |
| 4a | 2½-inch internal impinging jet with screen | 100 | * | * | * | * | * | * |
| | | 200 | 30 | 90 | 3/4 | 4 | 3 | 8 |
| | | 200 | 30 | 90 | 1 | 2 | 6 | 8 |
| | | 200 | 100 | 90 | 1/2 | 1 | 3 | 8 |
| | | 300 | 75 | 90 | 1 | 1 | 6 | 8 |
| | | 300 | 75 | 90 | 3/4 | 3 | 3 | 8 |
| | | 300 | 82 | 90 | 3/4 | 4 | 3 | 8 |
| | | 400 | 65 | 90 | 1 | 3 | 3 | 8 |
| | | 400 | 54 | 90 | 1 | 3 | 3 | 8 |
| | | 400 | 55 | 90 | 1/2 | 4 | 3 | 8 |
| | | 500 | 65 | 90 | 1 | 0 | - | 8 |
| | | 500 | 55 | 90 | 1 1/2 | 4 | 6 | 8 |
| | | 500 | 60 | 90 | 1 | 4 | 3 | 8 |
| 4b | 2½-inch internal impinging jet with stream shaper | 100 | * | * | * | * | * | * |
| | | 200 | 100 | 90 | 1/2 | 2 | 6 | 20 |
| | | 200 | 120 | 90 | 1/2 | 2 | 6 | 20 |
| | | 200 | 60 | 90 | 1 1/2 | 0 | - | 20 |
| | | 300 | 135 | 90 | 1/2 | 1 | 6 | 30 |
| | | 300 | 58 | 90 | 1 1/2 | 1 | 9 | 30 |
| | | 300 | 70 | 90 | 2 | 1 | 9 | 30 |
| | | 400 | 85 | 90 | 1 | 1 | 6 | 40 |
| | | 400 | 70 | 90 | 1 | 1 | 12 | 40 |
| | | 400 | 55 | 90 | 1 | 1 | 3 | 40 |
| | | 500 | 40 | 90 | 1 | 1 | 3 | 45 |
| | | 500 | 45 | 90 | 2 1/2 | 1 | 9 | 45 |
| | | 500 | 70 | 90 | 1 3/4 | 0 | - | 45 |
| 13 | 2½-inch straight stream aspirating foam nozzle with fan-shaped difusor | 100 | 75 | 90 | 1 | 0 | - | 15 |
| | | 100 | 65 | 90 | 1 | 3 | 3 | 15 |
| | | 100 | 30 | 90 | 1 | 3 | 3 | 15 |
| | | 200 | 70 | 90 | 1 1/2 | 0 | - | 15 |
| | | 200 | 50 | 90 | 1 | 3 | 3 | 15 |
| | | 200 | 50 | 90 | 1 | 2 | 3 | 15 |
| | | 300 | 40 | 90 | 2 | 0 | - | 20 |
| | | 300 | 55 | 90 | 2 | 4 | 3 | 20 |
| | | 300 | 45 | 90 | 1 1/2 | 2 | 3 | 20 |
| | | 400 | 43 | 90 | 2 | 2 | 3 | 25 |
| | | 400 | 35 | 90 | 2 | 2 | 3 | 25 |
| | | 400 | 35 | 90 | 2 | 2 | 3 | 25 |
| | | 500 | 30 | 90 | 2 | 2 | 3 | 25 |
| | | 500 | 35 | 90 | 2 | 2 | 3 | 25 |
| | | 500 | 30 | 90 | 2 | 2 | 3 | 25 |
| 19 | 2½-inch fan-shaped external impinging with diffusing orifices | 100 | 80 | 90 | 1 | 0 | - | 14 |
| | | 100 | 52 | 90 | 1 | 0 | - | 14 |
| | | 100 | 60 | 90 | 1 1/2 | 2 | 3 | 14 |
| | | 200 | 35 | 90 | 1 | 2 | 9 | 18 |
| | | 200 | 40 | 90 | 1 1/2 | 0 | - | 18 |
| | | 200 | 30 | 90 | 1 1/2 | 0 | - | 18 |
| | | 300 | 35 | 90 | 2 | 0 | - | 18 |
| | | 300 | 40 | 90 | 2 | 0 | - | 18 |
| | | 300 | 30 | 90 | 2 | 2 | 9 | 18 |
| | | 400 | ** | ** | ** | ** | ** | ** |

Note: With nozzle 2, 2½-inch external impinging jet with fan-shaped diffusor, measurable extinguishment could not be obtained at any pressure, because the foam disintegrated faster than it was produced.

* No runs were conducted at this pressure.

** Pressures of over 300 psi could not be obtained with this nozzle.

184-3-690

Fig. 21. Industrial naphtha (375 gal) being poured from tank truck into test pit through 50-foot hose $1\frac{1}{2}$ inches in diameter. This operation required approximately 15 minutes. Graduated stands shown here were used to estimate approximate depth of foam blanket upon successful extinguishment.

the nozzle was directed along the longer axis of the pool and 8 to 45 feet away from the near edge, depending upon the range of the nozzle (Fig. 23). These tests were conducted at pressures ranging from 200 to 500 psi inclusive, depending upon the pressure range of the nozzle under consideration.

The crash fire truck had to maintain high mobility during the actual fire tests so that it could be moved to safety in case the fire raged out of control and endangered the safety of test personnel and equipment. For this reason, the fire tests were conducted with 1000 gallons of 6-percent premixed solution, the full tank capacity of the crash truck, thus eliminating hose connections from the water system of the test area to the vehicle.

Within a few seconds after the industrial naphtha had been poured, all fires were ignited by throwing a lighted torch into the center of the fuel pool. Each fire was allowed 5 seconds preburn time before extinguishment was attempted, in order to compensate for variations in ambient temperature, humidity, and surface temperature of the fuel (Fig. 24). Observation of the foam pattern formed on the burning surface by each nozzle at the various pressures was not possible because the updraft currents, flames, and smoke obstructed a clear view (Fig. 25). The control time for each fire was recorded as the length of time in seconds from the initial application of foam required to cover an estimated minimum of 90 percent of the burning surface of the pool with a foam blanket. It was then possible to approach the pool with foam hand lines and obtain complete extinguishment, if desired. This criterion was used as a standard for all test fires. The thickness of the foam blanket was noted from the depth gauges shown in Figs. 21 and 26. Total extinguishment was not attempted in any of the tests. The remaining flickers were allowed to disintegrate the foam blanket slowly, and the fire was permitted to regain its original intensity (Fig. 27). This was considered as proof that the pool fire had not burned itself out but had actually been brought under control by the foam. In addition, it was an expeditious way to clear the pool of foam and naphtha for successive tests.

d. Results. The following data were collected from approximately seventy separate pool fires, each involving 375 gallons of industrial naphtha.

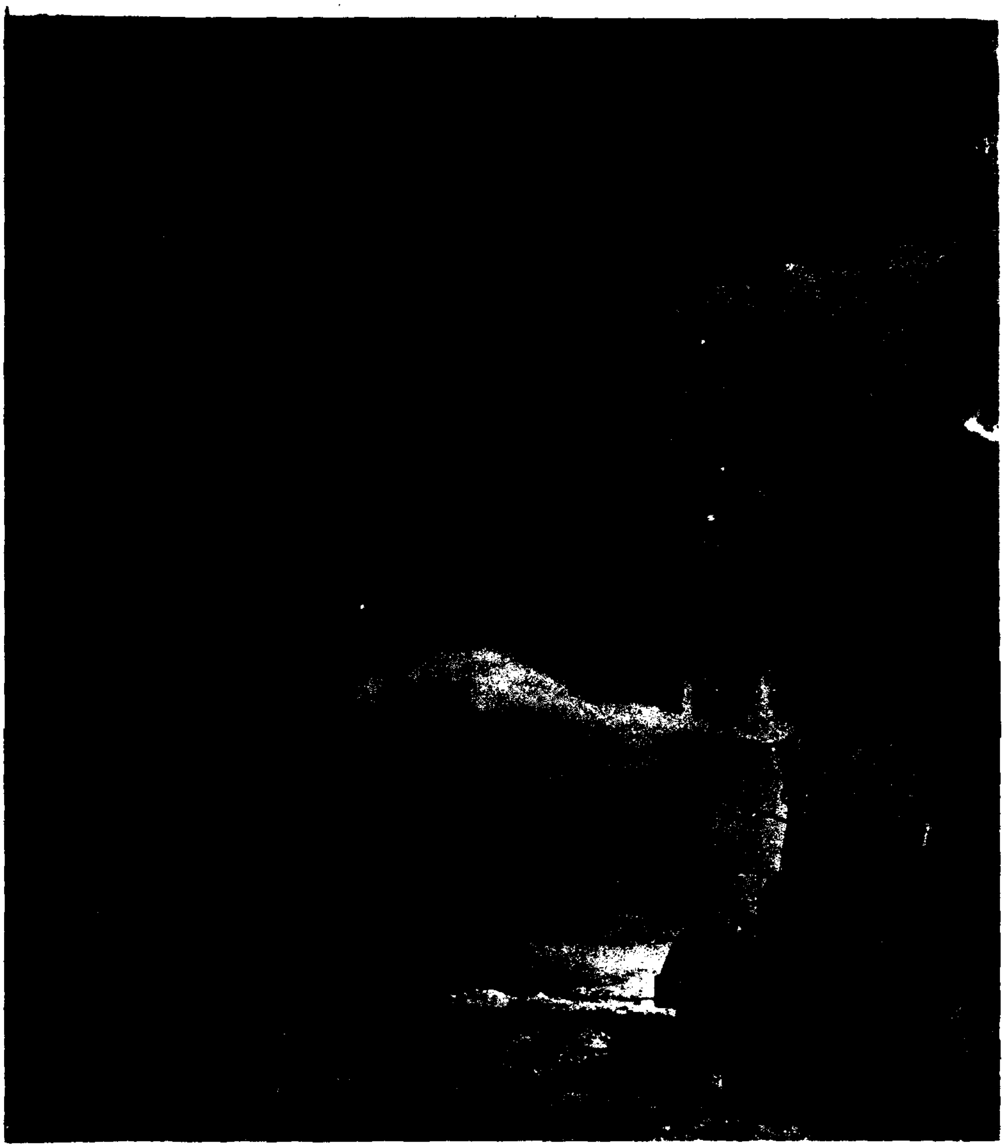
(1) Estimate of percent extinguishment.

(2) Control time.

(3) Foam blanket, thickness, and percent coverage.

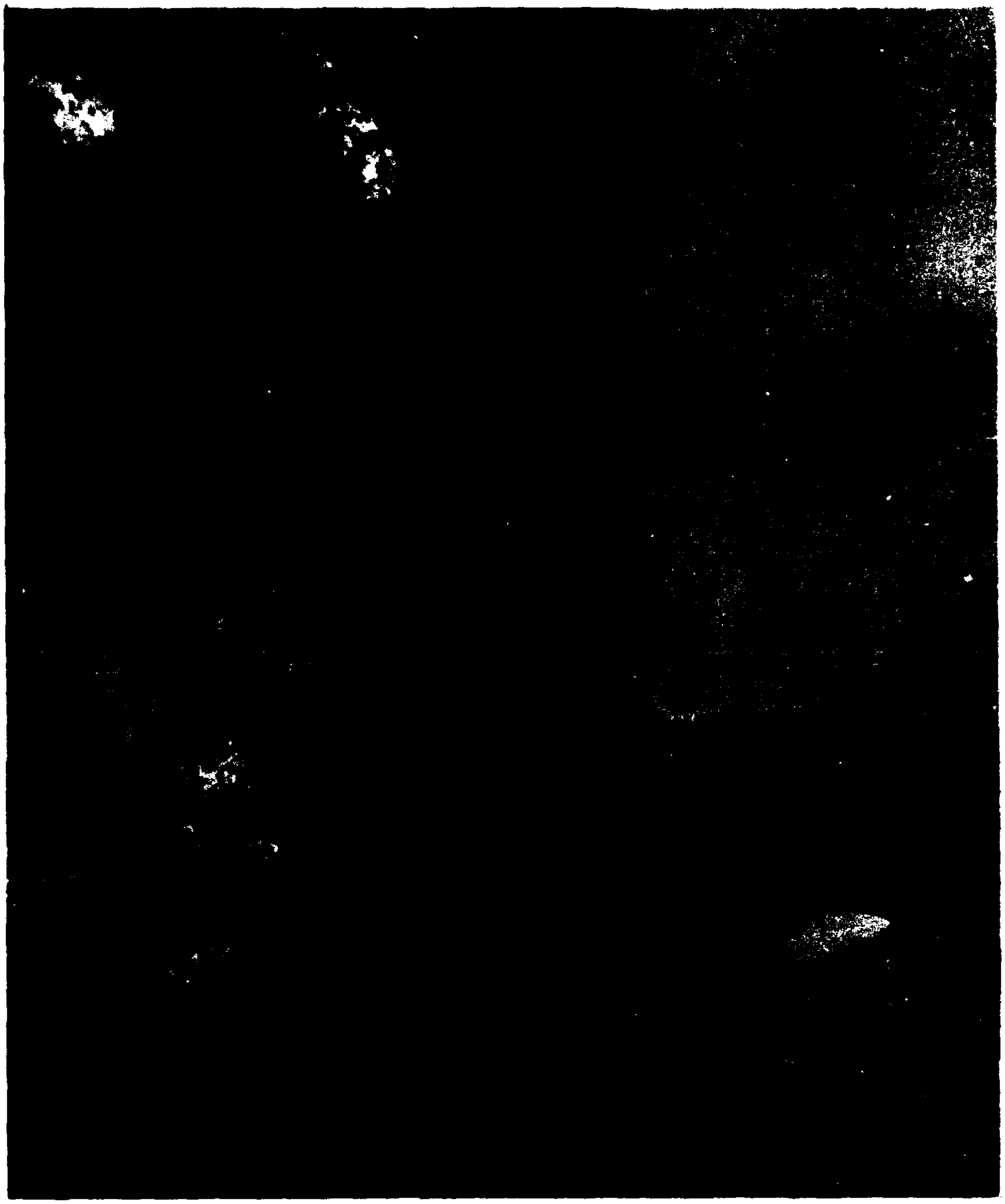
184-3-705

Fig. 22. Directing fog foam stream downward into pit, more than 10 degrees from horizontal, at higher pressures had tendency to dig and splatter burning liquid, causing turbulence and increasing intensity of fire. As illustrated here, inflammable fuel splattered beyond limits of pool, making it impossible to extinguish fire without additional equipment.



184-3-697

Fig. 23. Typical test run. Turret operator maintained constant pressure at nozzle throughout tests by control of pump speed. Driver kept motor running so that truck could immediately be moved to predetermined safety zone in case equipment and test personnel became enveloped by flames during sudden wind changes. Fire fighter in foreground is test crew chief and is in position to observe overall conduct and safety of each test. He timed each run and estimated extinguishment time.



184-3-699

Fig. 24. Large-scale pool fire approximately 8 seconds after ignition of 375 gallons of industrial naphtha in shallow pit 25 by 50 feet. Combustible liquid is burning at height of its intensity. Fog foam fails to show any results at this point because of its short period of application.

The following information explains items in Table III. Columns 1, 2 and 3 are the same as in the previous tables. The control time in seconds is listed in column 4. Percent extinguishment shown in column 5 refers to the estimated area of the burning pool where the foam blanket has extinguished the flames. In column 6, the depth of the foam blanket is given to the nearest quarter-inch reading on the depth gages shown in Figs. 21 and 26. The wind velocity in mph is listed in column 7. The direction of the wind, column 8 is tabulated in accordance with the clock dial system starting at 12 o'clock with the wind blowing directly into the nozzle against the expelled foam stream. In column 9, the distance from the tip of the nozzle to the near edge of the pit varied from 8 to 45 feet, to compensate for the variable range of the nozzles at the pressures indicated. Pressures for which no entries have been recorded in column 3, unless otherwise stated, were beyond the capacity of the equipment as set up for this phase of testing. Actual fire tests are shown in Appendix IF.

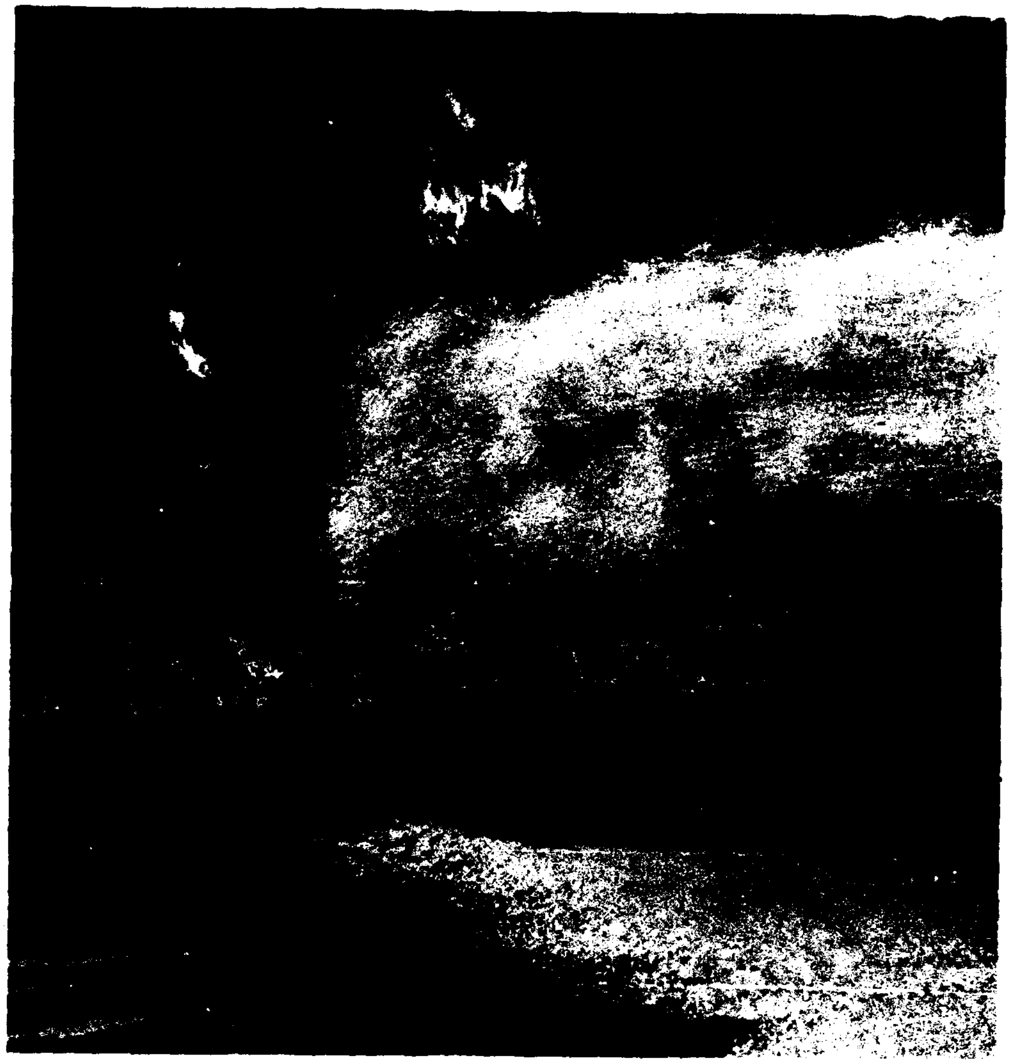
e. Observations. The average control time for each run is listed in Table IV. Pressures for which no entries were made indicate limitations of the test apparatus. The results indicate that any increase in pressure has a tendency to reduce the control time. Data presented in Table IV are plotted in Fig. 28. Each curve in this figure is clearly labeled to identify the nozzle which it represents in addition to being numbered for quick reference to Tables I, II, III, and IV. Fig. 22 illustrates a typical test in which control failed. More than 70 percent of the total surface area was enveloped in flames, radiating too much heat for proper application of foam with hand lines.

11. Report Film "Fog Foam Studies." A 16-mm color motion picture with narration, Report Film 1401, "Fog Foam Studies," was made indicating test procedures. This film may be obtained by written request to the Bureau of Aeronautics, Department of the Navy, Washington 25, D. C.

## III. DISCUSSION

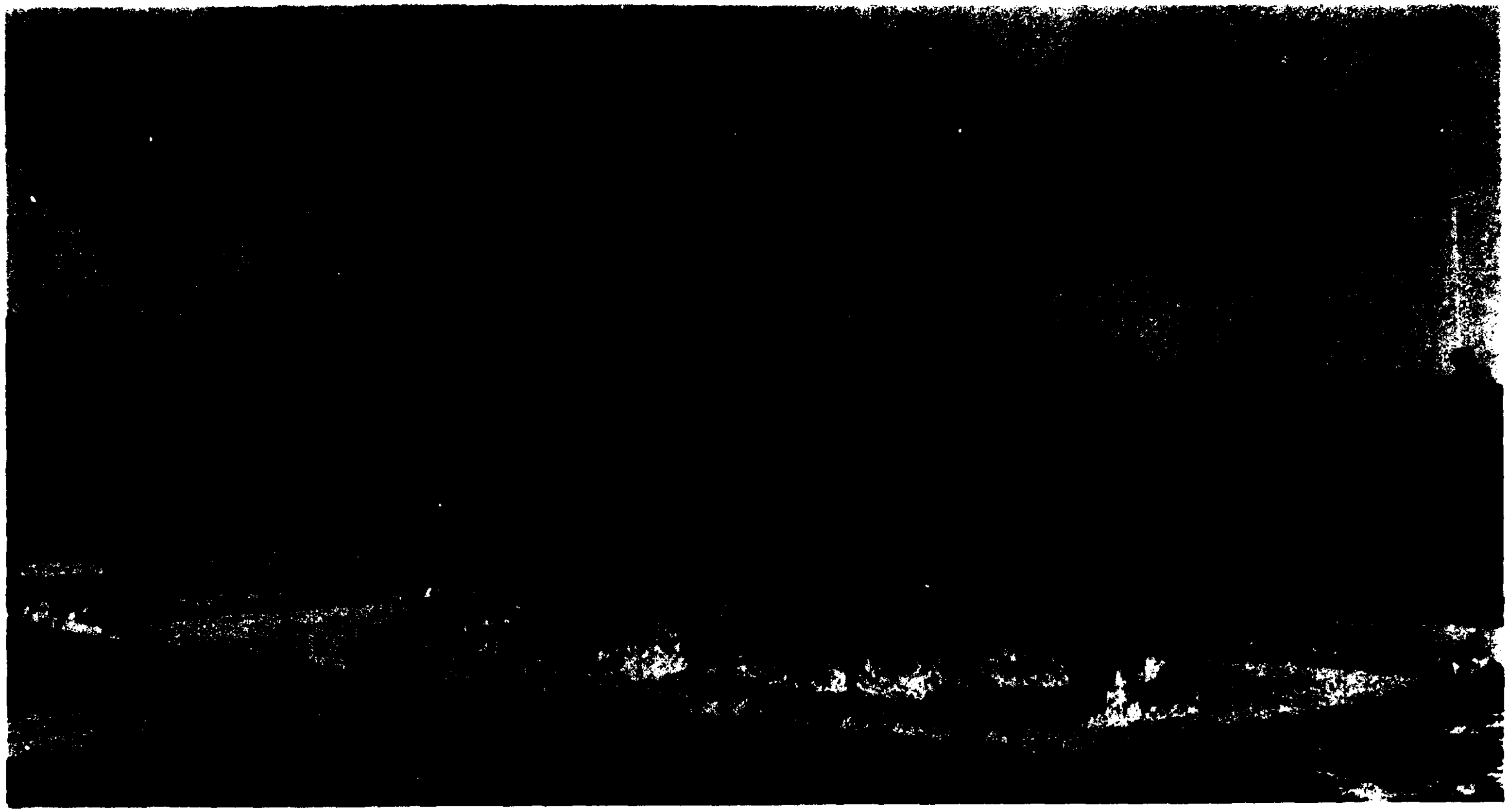
12. Nozzle Performance Tests. These tests were designed to obtain performance characteristics of various commercial and experimental nozzle arrangements prior to the actual fire tests. Variables in the test arrangements and conditions affected the final results to the point where individual items of the experimental data are not reliable; however, a study of the results as a whole indicates definite trends that must be considered.

Although the method used to determine the delivery rates of the premixed solution (measuring the depth of the liquid in the



184-3-701

Fig. 25. Looking into burning pit from across ground along side Class 155 crash fire truck during test, 15 seconds after initial application of fog foam at approximately 300 psi nozzle pressure. Foam, falling on ground between truck and burning pool, is a total loss. Note difficulty of determining pattern in initial stages of test, because updraft currents, smoke, and flames obscured action area from view.



184-3-706

Fig. 26. Condition in all fire tests when 375 gallons of burning naphtha was brought under control. This was standard condition in which fires were approximately 95 percent extinguished with turret-mounted, commercially available fog foam nozzle. Remaining flickers could easily be extinguished with foam hand lines. Note graduated metal stands placed throughout pit to estimate approximate depth of foam blanket.

184-3-700

Fig. 27. Remaining flickers which could easily have been controlled with foam hand lines were allowed to burn. These slowly disintegrated foam blanket, resulting in fire of original magnitude. This is condition of pool fire after it has gained full force in approximately 55 seconds and after it has been successfully brought under control with foam.

Table IV. Average Control Time of Pool Fires at Various Pressures

| Nozzle No. | Nozzle Type | Control Time (sec) Nozzle Pressure (psi) 100 | 200 | 300 | 400 | 500 |
|---|---|---|---|---|---|---|
| 1 | $2\frac{1}{2}$-inch external impinging jet | No | extinguishment | | | |
| 2 | $2\frac{1}{2}$-inch external impinging jet with fan-shaped diffusor | No | extinguishment | | | |
| 3 | $2\frac{1}{2}$-inch internal impinging jet | - | 88 | 76 | 51 | - |
| | $2\frac{1}{2}$-inch internal impinging jet with screen | - | 87 | 77 | 65 | 60 |
| 4b | $2\frac{1}{2}$-inch internal impinging jet with stream shaper | - | 93 | 88 | 70 | 52 |
| 13 | $2\frac{1}{2}$-inch straight stream aspirating foam nozzle with fan-shaped diffusor | 73 | 57 | 47 | 38 | 31 |
| 19 | $2\frac{1}{2}$-inch fan-shaped external impinging with diffusing orifices | 63 | 35 | 35 | - | - |

tank before and after a test) was not very accurate at low flow rates, it was the most expedient and, in fact, the only method available at the time the tests were conducted. In order to insure a 6-percent foam concentration, a premixed solution must be used, as the low-range foam proportioner does not perform accurately below 60 gpm. On the other hand, the use of a premixed solution for nozzles with delivery rates above 60 gpm was impractical; therefore, foam proportioning equipment preset at a 6-percent rate was used.

The variations listed in column 9 of Table I were partly caused by experimental error, slip in the rotors of the proportioner, leakage of the vacuum in the suction line, or some combination of these factors.

The effect of pressure on the foam yield, observed in the studies of the screening tests, was of paramount importance. The foam yield is at a maximum between 200 and 300 psi for any nozzle.

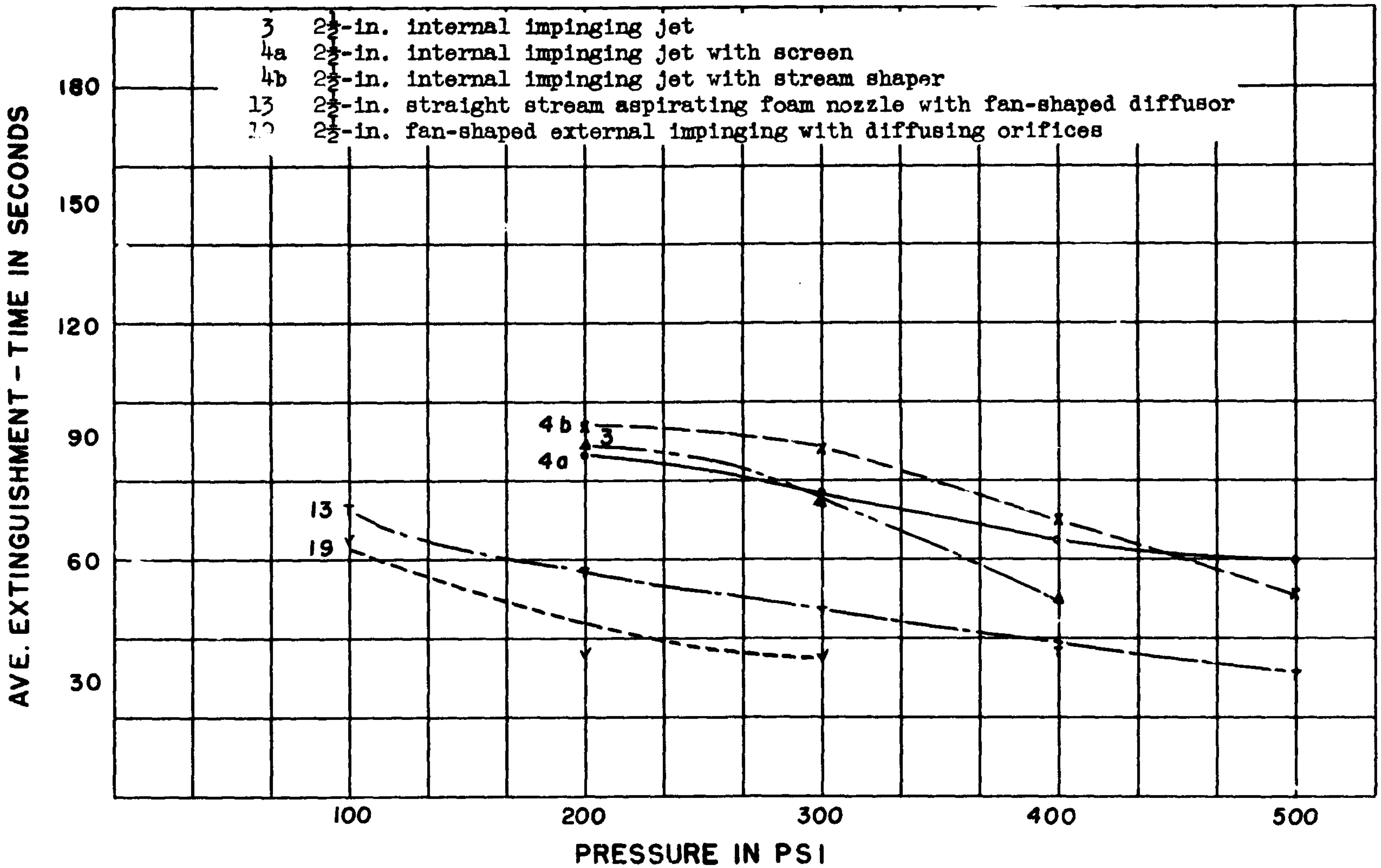



Fig. 28. Average extinguishment time vs. nozzle pressure (Table IV) for nozzles 3, 4a and b, 13, and 19.

The pressure producing the maximum yield varies with the individual nozzle, as does the rate of decrease after the maximum has been reached. Although the foam yield decreases above the range between 200- to 300-psi nozzle pressure, in most instances the total amount of foam produced per unit time continues to increase up to 500 psi. This is corroborated in column 6 of Table II. During the tests, it was observed that the liquid flow through the nozzle occasionally did not increase as the pressure increased. Upon investigation, it was found that sand and small particles of gravel present in the water had partially clogged the orifices and screens. The variations in Table II resulted from the clogging of the nozzles, from the experimental error of measuring flows, from inaccurate measurement of the foam blanket, and from the expansion determination used to calculate theoretical volumes of foam produced.

Data presented in Table II and in the sample data sheets (Appendix IC) indicate variations in the foam expansion which do not correlate with run conditions. These variations are, in part, a result of small delays by the test personnel in obtaining samples. For example, if the pattern depth were small, 30 seconds might have been consumed in obtaining the sample; this time allowed for some drainage of the foam, thereby raising the apparent foam expansion. To some extent, this contributed to the higher expansions recorded for low-pressure (small pattern volume) runs. Normally, the expansion appeared to vary by 10 to 15 percent within an individual foam pattern. For most of the nozzle arrangements tested, the highest foam expansion and, hence, the lowest foam yield, was generally obtained at low discharge pressures. This occurred because the foam yield is, in part, based on a theoretical foam volume caluclated from the consumption of foam solution and from the expansion factor. That is, higher expansion factors give higher theoretical foam volumes which, in turn, indicate lower foam yields. However, it was noted that the foam yield increased with the water pressure, but decreased as the highest test pressures were approached.

Variations in the drainage rates, ranging from 10 to 20 cc per minute, indicate that the test procedure for obtaining these rates is more vulnerable to experimental error than is the expansion factor determination. As has been stated, delays in obtaining samples, or in collecting the drooled foam solution from the ground surface, account for the greater part of the variations of data.

The direction of the wind and its velocity must be considered also. Wind has a spreading effect on the fog foam discharge because the small mass of the finely divided particles is easily deflected in comparison to a solid stream. This fact is verified by the results of the tests. The width of the pattern (the dimension taken horizontally and at right angles to the stream), in general, remained almost the same at all pressures, whereas the length of the pattern (the dimension of the pattern along the axis of the stream flow) increased slowly as the pressure increased. In column 10 of Table I, the largest pattern area is occasionally indicated at the lower pressures, because of sudden changes in wind direction.

The solid stream aspirating foam nozzle gives the highest foam yields. In general, those nozzles which produce the best water fog were observed to produce very low foam yields.

13. Fire Tests. The fire tests, employing pool fires involving 375 gallons of industrial naphtha, were chosen as being representative of the heat conditions encountered in crash fire fighting. The success in extinguishing liquid fuel fires depends on the rapidity with which the foam blanket is applied over the entire burning surface in order to exclude air and radiant heat, thus preventing further evaporation and combustion of the flammable liquid in the immediate danger area.

On a fire of the size just described, it is not feasible to set the nozzle horizontally to the ground and to expel the foam so that it falls downward on to the burning area. When this was done during the tests, it was found that the smaller particles of foam were dissipated and the larger ones were carried from 50 to 250 feet from the burning surface, so that the small remaining amount of foam reaching it was quickly disintegrated by the heat. Therefore, it was necessary to lower the nozzle approximately 10 degrees, thus increasing the downward velocity of the foam so that it penetrated the updraft currents and created an extinguishing blanket over the pool. Lowering the nozzle further, however, tended to create turbulence and to splatter the fuel about the burning area, as has been indicated in Fig. 22.

In view of the fact that fog nozzles have limited reach, it was necessary to fight each fire at close range. Since the vertical pattern of the fog nozzle was larger in area than that of a solid stream, it was affected more by any shift in the direction of the wind. Significant changes in the wind direction and velocity displace the foam pattern by throwing the foam outside the pool boundaries and make it impossible to control the fire. On several occasions while a test was in progress, the wind shifted direction 180 degrees. Under these conditions it was impossible to obtain control, and no data were recorded.

Fig. 28 indicates that with increases in pressure up to 500 psi the extinguishment time decreases. This behavior is explained by the fact that even though the foam yield is lower at the higher pressures, the total amount of foam produced is increased and the application rate is greater than the destruction rate. Therefore, an effective foam blanket is more quickly applied.

# Table V. Performance Data of Nozzles Tested on Actual Fires

| 1 Nozzle No. | 2 Nozzle Type | 3 Nozzle Pressure (psi) | 4 Water Rate (gpm) | 5 Control Time (sec) | 6 Fire Area (sq ft) | 7 Gross Water Distribution on Fire Area (gpm/ft$^2$) | 8 Percent Foam Yield | 9 Expansion Ratio | 10 Foam Distribution on Fire Area (gpm/ft$^2$) | 11 Water Content of Foam Distribution on Fire Area (gpm/ft$^2$) | 12 Water Content of Foam Required per Sq Ft of Fire Area |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2½-inch external impinging | 300 | 150 | Infinity | 1250 | .12 | 43 | 6.9 | .35 | .050 | Infinity |
| | jet | 400 | 180 | do | 1250 | .14 | 37 | 6.8 | .35 | .050 | do |
| 2 | 2½-inch external impinging jet | 200 | 160 | do | 1250 | .13 | 18 | 10.4 | .24 | .023 | do |
| | with fan-shaped difusor | 300 | 170 | do | 1250 | .13 | 15 | 7.7 | .16 | .019 | do |
| 3 | 2½-inch internal impinging | 200 | 260 | 83 | 1250 | .21 | 28 | 5.4 | .32 | .058 | .055 |
| | jet | 300 | 310 | 76 | 1250 | .25 | 27 | 7.1 | .48 | .068 | .086 |
| | | 400 | 370 | 51 | 1250 | .29 | 31 | 5.3 | .48 | .090 | .078 |
| 4a | 2½-inch internal impinging | 200 | 190 | 57 | 1250 | .15 | 62 | 5.8 | .54 | .092 | .133 |
| | jet with screen | 300 | 200 | 77 | 1250 | .16 | 53 | 5.6 | .47 | .085 | .109 |
| | | 400 | 220 | 65 | 1250 | .18 | 51 | 6.2 | .57 | .092 | .100 |
| | | 500 | 256 | 60 | 1250 | .20 | 36 | 7.2 | .52 | .072 | .072 |
| 4b | 2½-inch internal impinging | 200 | 180 | 93 | 1250 | .14 | 65 | 9.3 | .85 | .091 | .141 |
| | jet with stream shaper | 300 | 200 | 88 | 1250 | .16 | 54 | 6.6 | .57 | .081 | .128 |
| | | 400 | 215 | 70 | 1250 | .17 | 54 | 8.7 | .80 | .092 | .107 |
| | | 500 | 250 | 52 | 1250 | .20 | 44 | 7.1 | .63 | .088 | .076 |
| 13 | 2½-inch straight stream | 100 | 170 | 73 | 1250 | .14 | 58 | 9.9 | .80 | .081 | .099 |
| | aspirating foam nozzle with | 200 | 218 | 57 | 1250 | .17 | 72 | 3.2 | 1.00 | .122 | .115 |
| | fan-shaped diffusor | 300 | 250 | 47 | 1250 | .20 | 73 | 7.3 | 1.06 | .145 | .114 |
| | | 400 | 290 | 37 | 1250 | .23 | 70 | 7.2 | 1.16 | .161 | .101 |
| | | 500 | 310 | 31 | 1250 | .25 | 64 | 7.4 | 1.18 | .160 | .083 |
| 19 | 2½-inch fan-shaped external | 100 | 240 | 53 | 1250 | .19 | 47 | 10.7 | .95 | .089 | .092 |
| | impinging with diffusing | 200 | 300 | 35 | 1250 | .24 | 54 | 9.4 | 1.22 | .130 | .076 |
| | orifices | 300 | 340 | 35 | 1250 | .27 | 45 | 7.8 | .95 | .120 | .070 |

Note: The data in column 7 are quotients derived from the data in column 6 divided by the data in column 4.

The data in column 10 are the products of the data in columns 7, 8, and 9.

The data in column 11 are the products of the data in columns 7 and 8.

The data in column 12 are the products of the data in columns 5 and 11.

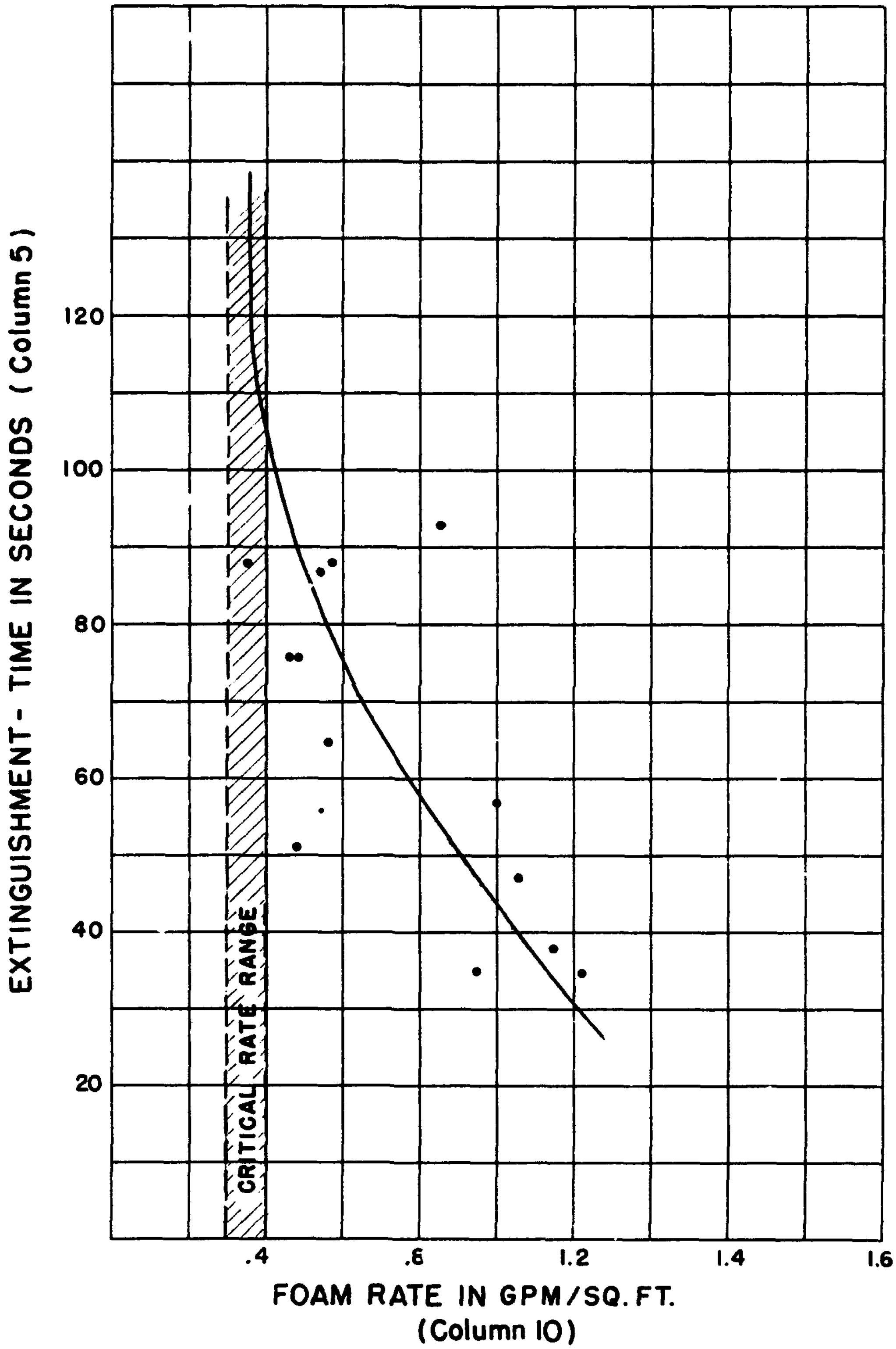



Fig. 29. Extinguishment time vs. rate of foam application per unit area.

Nozzles 1 and 2, which exhibited the lowest foam yields in the screening tests, failed to extinguish the pool fires because the resultant rate of actual foam application was less than the critical rate required for extinction. This fact, confirmed in Table V and in Fig. 29, demonstrates the importance of foam yield in nozzle performance.

14. General Factors Considered in Nozzle Evaluation. The factors influencing the experimental data and the effect of nozzle discharge pressure on the foam yield have already been discussed. In the following subparagraphs are considered the factors found during the tests to have a critical effect on nozzle performance.

a. Foam Yield. A low foam yield indicates that a high percentage of the foam solution discharged from the nozzle will, if it reaches the burning surface, drop through the liquid fuel, and have no further effect in extinguishment. However, these solution particles not in the air dispersion will be of benefit in cooling the flame zone as does water fog, thus providing protection to fire fighting personnel, without contributing significantly to final extinguishment. The information presented in Table V, derived from the test data in Tables I through IV, indicates that for two nozzles of nearly equivalent water consumption rates, the nozzle 1, displaying a lower yield failed to extinguissh the test fire, because its foam rate in gallons per minute per square foot of burning area was less than the critical rate required for extinguishment (Fig. 29).

As indicated in Table V, foam producing appliances should display a minimum foam yield of 50 percent.

b. Quality of Foam. The effect of the quality of foam is seen in part by close examination of Figs. 29 and 30. The abscissas of the points in Fig. 29 differ from those in Fig. 30 by the expansion factor of the foam (column 9, Table V). The plotted experimental data in Fig. 30 is grouped closer to the apparent function than in Fig. 29. This indicates that the critical quality of the foam in the expansion range of 6 to 9 may be best taken as the water content; that is, the heat dissipation ability of the foam is directly proportional to the water content of the foam per unit volume.

Since the expansion range did not vary appreciably from nozzle to nozzle, the effect of the foam expansion was not of immediate concern in this study. The stability (drainage rates) did not vary appreciably with the nozzle type of pressure in the items tested, so that the effect of this foam quality cannot be derived in this study. The expansion range and drainage rates as recorded in this study must be accepted as fixed in order to evaluate such variables as water content of foam applied per unit area, extinguishment time, and pattern characteristics.

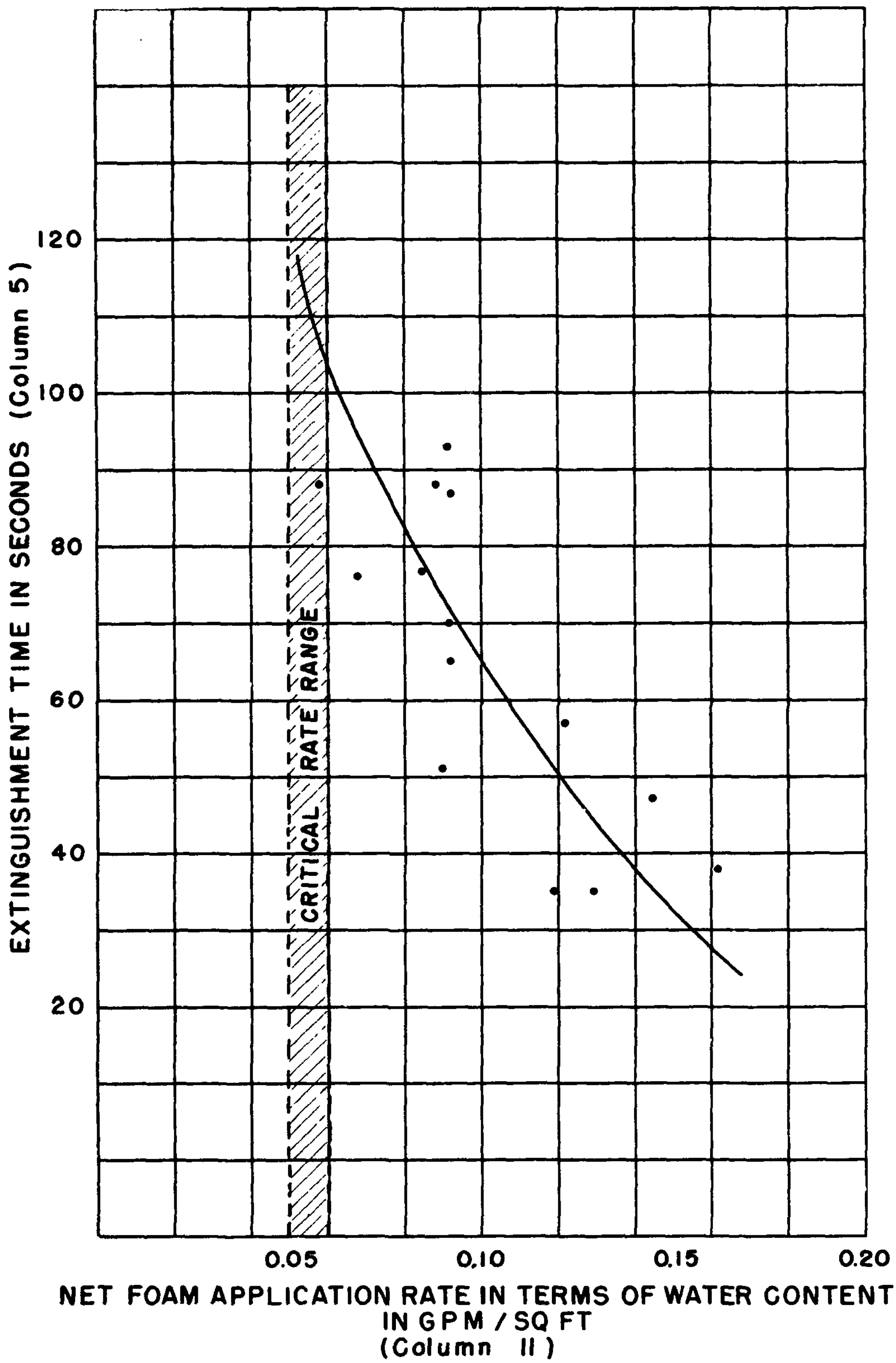



Fig. 30. Extinguishment time vs. net foam application rate in terms of water content per unit area.

c. Rate of Application. Fig. 29 and 30 also indicate that extinguishment time is approximately inversely proportional to the specific application rate. As previously stated (par. 14b), the water content of the foam was selected as the criterion of its quality. Close examination of Fig. 29 indicates that .4 gpm per square foot of burning surface is the critical rate of foam application required to obtain extinguishment. Control was assured when the rate was increased to .5 gpm per square foot and this figure includes only a very small factor of safety necessary for adverse conditions. It may, therefore, be stated that .5 gpm per square foot constitute the minimum application rate for proper control. This value may be used to estimate flow rates required for individual appliances for crash fire fighting.

The more efficient the nozzle is as a foam producer, the less water it uses. From this, and from an observation of Fig. 30, it appears that the critical water rate is .06 gpm per square foot of burning area, and that a minimum rate of .08 gpm per square foot is desirable. The function presented in Fig. 30 should be of value in ascertaining equipment needs for crash fire fighting apparatus.

Fig. 30 also reveals that extinguishment time is a function of the product of foam yield and rate of water flow to the fog foam nozzle.

d. Quantity of Foam. The net foam application rate based on water content (gpm per square foot) was compared with the quantity of foam required to extinguish the fire (also based on water content in gallons per square foot). While the experimental data showed no apparent correlation, the data calculated from the curve of Fig. 30 showed that less foam was necessary for extinguishment at high application rates. An increased rate of application will reduce the time required to extinguish the fire more than it will reduce the total amount of foam needed.

15. Summary of Test Findings. A number of significant findings were derived as a result of the tests, each of which bears on the effectiveness of the nozzles tested and the quality of the foam produced.

a. The foam yield percent is generally highest in the nozzle pressure range between 200 and 300 psi.

b. The total output of foam from the various nozzles increases with pressure.

c. For a given nozzle, the width (minor axis) of the foam pattern increases only slightly with an increase in discharge pressure, whereas the length (major axis) increases appreciably.

d. The specific application rate of foam was critical from the standpoint of fire extinguishment. A critical rate, based on the water content of the actual foam produced, was .06 gpm of water per square foot of burning area.

e. The extinguishment time in seconds proved to be essentially inversely proportional to the foam application rate in gallons per minute per square foot of critical rate (par. d).

f. The quantity of foam per unit area required for extinguishment tends to decrease as the application rate increases.

16. Optimum Nozzle Design. Three major categories of nozzles were tested: foam, water fog, and fog foam. As indicated by the results of these studies, standard foam nozzles produced the highest foam yields because each was designed to entrain air into the foam solution before it was discharged into the air. This resulted in more of the foam solution being converted into the active extinguishing agent foam. However, no standard foam nozzle could be adopted satisfactorily for use as a straight stream nozzle or as a water fog nozzle.

The water fog nozzles (par. 7) were designed to produce a fine water mist at pressures of 100 psi and above. Air is not entrained into the water stream, which is necessary if a high foam yield is to be expected. The overall performance of these nozzles in producing fog foam was unsatisfactory; their effectiveness varied widely from nozzle to nozzle, the best water fog nozzles generally producing the poorest fog foam.

Only one nozzle in the group tested was designed as a combination water fog and fog foam nozzle, which was designed as a combination of the two categories just discussed. The entrainment of air was effected by a screen attachment with four slots at the base. This nozzle produced the highest foam yields at the optimum pressures of 200 to 300 psi, confirming the theory that entrainment of air is necessary to produce high foam yields with fog foam nozzles.

17. Standards of Nozzle Performance. One of the specific objectives of this investigation was to develop standards of performance for fog foam nozzles so that they could be evaluated quickly and without the necessity of employing expensive fire tests. While the absolute values derived on the basis of the tests conducted are admittedly somewhat arbitrary, it was found that nozzles having the following characteristics afforded sufficient protection for personnel and equipment to attack and extinguish the types of fires conducted in this investigation. A diagram illustrating these characteristics is shown in Fig. 31.

a. Turret-mounted Nozzles. Standards of performance for turret-mounted fog foam nozzles are:

(1) Angle of dispersion of the fog foam pattern should be not less than 30 nor more than 40 degrees.

(2) Maximum working nozzle pressure should range between 200 and 300 psi.

(3) When the nozzle produces fog foam at rated pressure and water delivery, and is located parallel to, and 12 feet above, ground level in still air, 80 percent of the foam should fall at a distance greater than 12 feet, measured from a point on the ground determined by a vertical line from the tip of the nozzle to the ground.

(4) Pattern size under the conditions stated in (3), should be between the following limits:

(a) Minor axis not less than 14 feet.

(b) Major axis not less than 30 feet.

For lower delivery rates, the major axis should be foreshortened in proportion to the reduction in the delivery rate.

(5) Foam yield should be 50 percent or over.

(6) Average expansion factor should not exceed 9.

(7) Drainage rate should be less than 18 cc per minute during the period from the first to fourth minute after the sample is obtained.

b. Hand and Bumper-mounted Nozzles. Standards for hand and bumper-mounted nozzles are identical with those in subpar. a (subpar. a(3) and a(4) do not apply) with the following limitations:

(1) Water delivery rate should range between 25 and 30 gpm.

(2) The maximum working nozzle pressure should not exceed 250 psi for hand lines (one fire fighter) and 300 psi for bumper-mounted nozzles.

18. Proposed Test Procedure. In order to ascertain the conformance of a nozzle to the standards established, several screening test procedures were considered prior to the adoption of that set up in par. 9b. The latter test proved to be a satisfactory means of

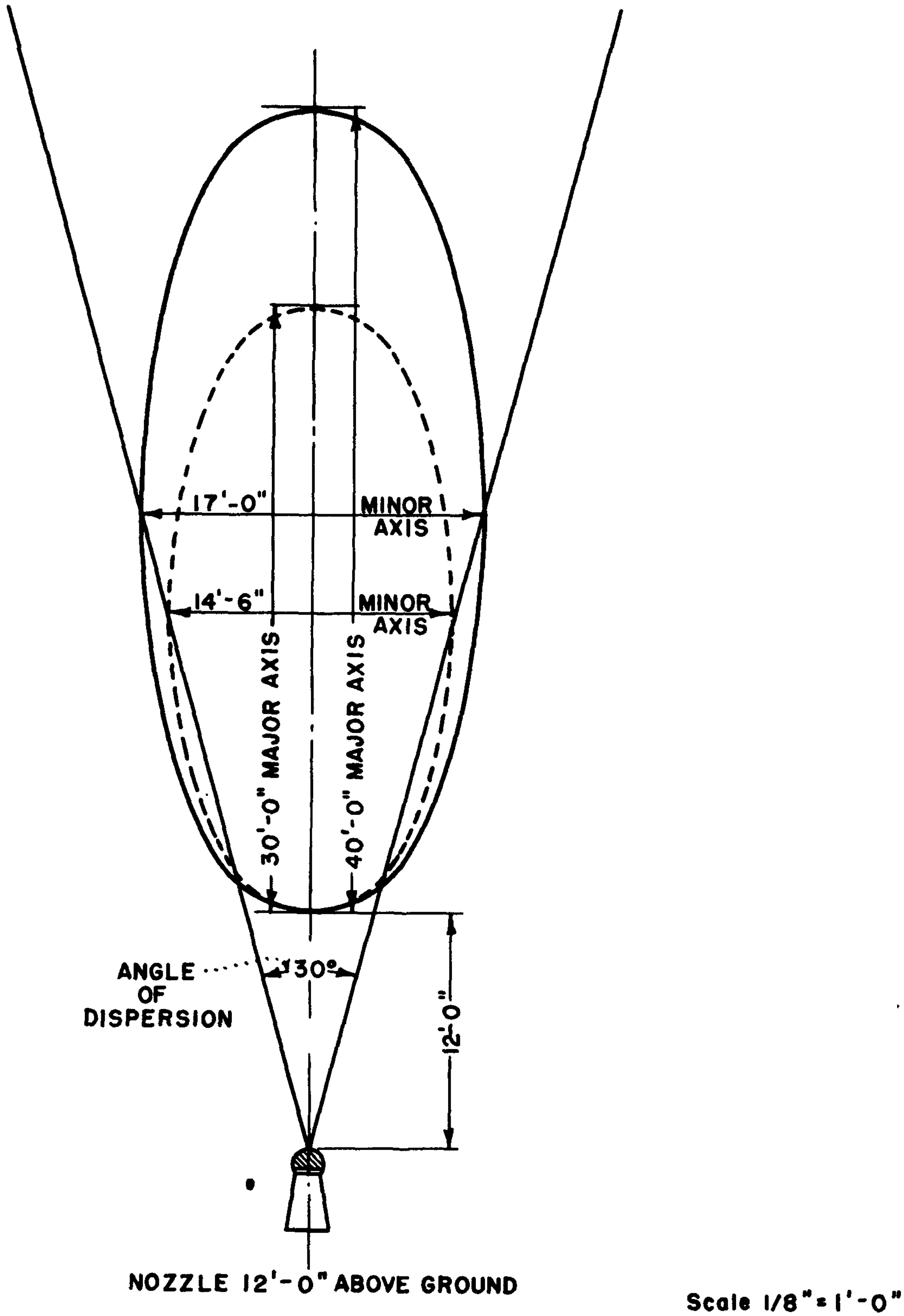



Fig. 31. Pattern characteristics for fog foam nozzles.

determining the pattern, foam yields, and general hydraulic characteristics of the nozzles, as was demonstrated by the excellent correlation of the screening test and fire test results. Testing the nozzles in accordance with the screening tests (par. 9) facilitates and expedites the nozzle evaluation by the elimination of costly fire tests.

19. Considerations for Future Investigation. During the course of this investigation, a generated-foam system (in which the foam liquid, water, and air are mixed in predetermined proportions) was evaluated under another project on a 700-gallon pool fire in a square pit measuring 50 by 50 feet. The system employed a Hale foam generator with a rated capacity of 2000 gpm of foam at a predetermined 4:1 expansion. Both the quality of foam and the control time required appeared to be somewhat more favorable than that obtained using fog foam nozzles. With the generated foam system mentioned, a smooth-base 1 3/4-inch nozzle was used at a distance of approximately 120 feet from the edge of the burning pit. The foam stream was played approximately on the center of the pool to build up a fast spreading blanket. By this method, the fire could be controlled from a greater distance, affording increased protection to personnel and equipment. Studies to compare the merits of a generated foam system, using a predetermined blowup, with those of fog foam application, warrants further investigation.

Since the tests have indicated that the rate of foam application is a major factor in time of extinguishment, the use of higher delivery rates at nozzle pressures ranging from 200 to 300 psi should be investigated. It is possible that more efficient equipment would result from such a study.

## IV. CONCLUSIONS

20. Conclusions. It is concluded that:

a. The fire extinguishing effectiveness of fog foam nozzles is indicated by the following standards:

(1) Foam yield percent.

(2) Rate of application.

(3) Water content of foam (6 to 9 expansion) output in gallons per minute.

b. The test procedure set forth in the screening tests (par. 18) is a satisfactory means of evaluating the fire fighting effectiveness of fog foam nozzles.

c. On the basis of the foam used and the nozzles employed, the most effective nozzle pressure was between 200 and 300 psi.

d. The aspirating type nozzles produced higher foam yields than the non-aspirating type.

## V. RECOMMENDATION

21. Recommendation. It is recommended that the standards of performance and the test procedures presented in this report in pars. 17 and 18, respectively, be adopted by the Department of National Defense for use in the design of fog foam nozzles and in their evaluation for fire fighting.

Submitted by:

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Approved 2 April 1950 by:

Kenneth J. Cramsie

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Department

# APPENDIX IA

## LIST OF CALCULATIONS

## LIST OF CALCULATIONS

Calculations used in the fog foam study:

(1) Water used per run:
gallons water = (gpm rotometer reading)x(test time)

(2) Foam liquor used per run:
gallons foam liquor = (inches of drum level change)x (drum factor)

(3) Foam expansion:
Expansion = 1400 cc's resultant solution, in standard pan (cc's). See Part (1), Appendix D.

(4) Theoretical foam volume produced per run:
gallons foam volume = (gallons water + gallons foam liquid)x(average expansion)

(5) Actual foam volume produced per run:
gallons foam volume = (area of foam pattern, sq ft)x (ave. depth of foam in pails, ft)x(7.48)

The area of the foam pattern was obtained by mechanically integrating the pattern area as recorded on the data sheet. It can be seen that the "end effect" of the pattern is ignored by this method of calculating foam volume; however, the error is well within the general precision of the determination, i.e., the precision of recorded pattern area.

(6) Foam yield per run:

$$\text{foam yield} = \frac{\text{actual volume foam}}{\text{theoretical volume foam}} \quad \text{i.e.,} \quad \frac{(5)}{(4)}$$

(7) Foam drainage rate:

$$\text{drainage rate} = \frac{\text{cc's drained from 1400 cc pan, 1st to end of 4th minute}}{3\text{ (minutes)}}$$

In standard pan, see Part (2), Appendix D. Charts for procedures (2) and (3) were prepared for use by test personnel in performing the calculations during the test. Procedures (4), (5), (6), and (7) were not calculated at the time of the test.

# APPENDIX IB

## FOAM TEST PROCEDURE

## FOAM TEST PROCEDURE

Foam test procedures follow:

(1) Expansion Ratio Determination. The 2- by 7 3/8-inch diameter pan as described in Report of Foam Standardization Methods, by the Naval Research Laboratory, is used in this determination. The volume of this pan is essentially 1400 cc's.

A representative foam sample is taken from the foam blanket in the pan as described in the report, and the excess foam is scraped from the top of the pan. One half cubic centimeter of octyl alcohol is added, and the contents are carefully stirred until the liquid-air dispersion is broken down. The pinch clamp on the drain spout is then removed and the solution is drained into a cylinder graduated in cubic centimeters. The volume of liquid is read, and the expansion is given by:

$$E = \frac{1400}{\text{cc's liquid}}$$

The test set up is shown in Fig. 13.

(2) Drainage Rate Determination. The apparatus as described above with the addition of a stop watch is used in this determination.

A sample is obtained as in the procedure, previously mentioned, and at the instant of obtaining the sample, the stop watch is started. The pan is placed on the drainage rack with a 6.5 percent sloping top as soon as possible and the drain is opened, permitting the separated solution to be collected in a graduated cylinder. Readings of the cubic centimeters of liquid collected are made each 15 seconds until 4 minutes have elapsed. At the end of the 4 minutes lapsed time, the remaining dispersion is broken down by a few drops of octyl alcohol. The resultant solution is drained into that collected in the first 4 minutes, so that the total volume of the solution is read, and the expansion of the original sample is determined by the formula presented in (1).

In these tests after 4 minutes had elapsed, it was noted that the drainage rate decreased, and the time required for one quarter drainage (index as proposed in Report on Foam Standardization Methods) occurred within this 4-minute period. In most instances, the first reading was at 45 seconds or one minute lapsed time, so that the drainage rate is taken as the cubic centimeters collected from the 1st minute to the end of the 4th minute lapsed time divided by 3. In this study the drainage rate is used as a criterion of foam stability. If it is desired to estimate the time for one quarter drainage, as used by the NRL, the following formula may be used:

$$T_q = \frac{1400}{4RE}$$

$T_q$ = time for quarter drainage

R = drainage rate as described here

E = foam expansion as described here

The deviations from the basic procedure as outlined by the NRL were made in order to adapt the tests to field determination which can be accomplished readily by other than technical personnel.

# APPENDIX IC

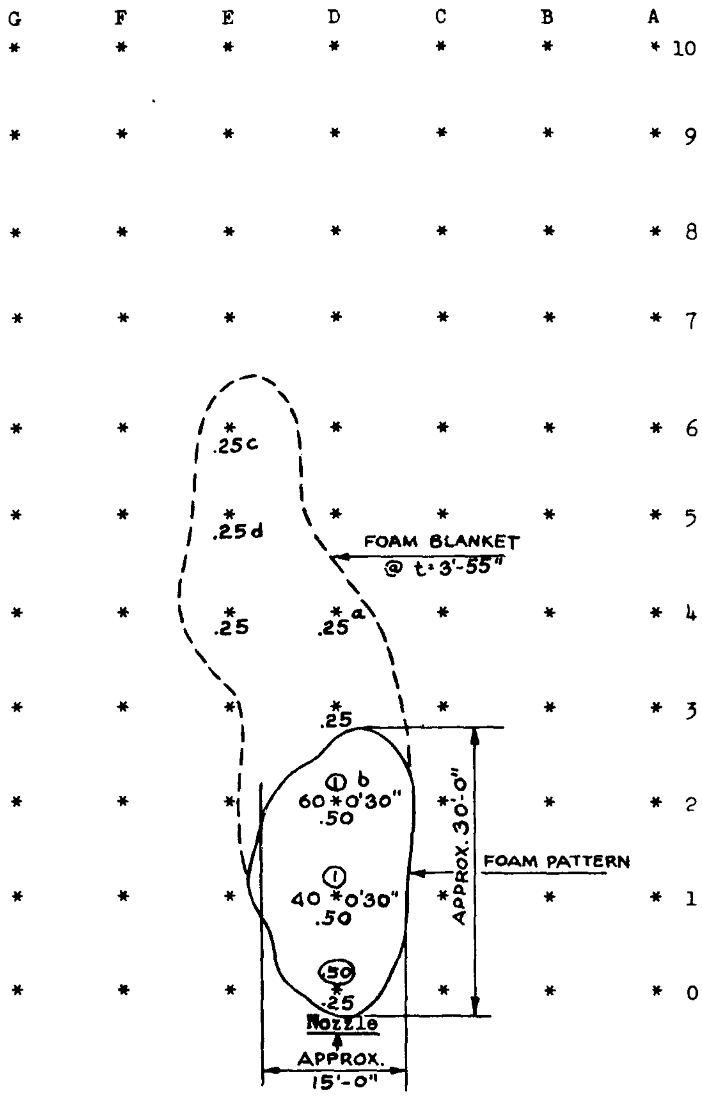
## SAMPLE DATA SET

Evaluation of $2\frac{1}{2}$-inch, internal impinging jet
with screen from 100- to 500-psi nozzle pressure

FOG FOAM STUDIES DATA SHEET

Project No. 8-76-01-001 (9)
Date 21 JUNE 1949
Humidity 76%
Temp. during test 85
Weather SUNNY, CLEAR
Test area 60' x 100'
Stakes 10' apart

Run No. 16
Nozzle 2½" INTERNAL IMPINGING JET WITH SCREEN




Procedure:
Premix ______
Metered flow ✓
Pressure:
a. Proportioner 90 psi
b. Nozzles 100 psi
c. Proportioner used 120
Rotometer LOW RANGE
Water flow 150 gpm
Time of run min 30 sec
Tot. water used 75 gal
Tot. liquid used 2.75 gal
%Foam solution 3.67

Blowup at points below:
a. 10.30
b. 1.85
c. 9.20
d. 8.05
Ave. 8.9

Stability - Min/25% drain
a. ______
b. ______
c. ______
d. ______
Ave. ______

% Solution
a. ______
b. ______
c. ______

Area
Pattern 380 $Ft^2$
Blanket 955 $Ft^2$

Ave. Foam Depth
Pattern .068 Ft.
Blanket .025 Ft.

Tot. Foam
Vol. Pattern VP 26 $Ft^3$
Vol. Blanket VB 24 $Ft^3$
V.E. = 89 $Ft^3$

VE = tot. vol. water plus foam liquor times ave. blowup

Eff. $= \frac{VP}{VE} = \frac{26}{89} =$ 29.2%

Key
* - Stake
X - Bucket (50 x 3'55")
50cc's drainage - X bucket - 3'55" time after end of foam application

Wind Direction

Velocity 5.5 mph

Data Sheet Recorder J. ALLEN

FOAM ANALYSIS

By: C. Korzendorfer

Project: 8-76-01-001 (9)

Run No.: 16

Date: 25 June 1949

| Location: | | Drainage 4-D | | 2-D | | Blow up 6-E | 5-E |
|---|---|---|---|---|---|---|---|
| CC's | Time | CC's | Time (sec) | CC's | Time (sec) | | |
| | | 10 | 45 | 22 | 45 | | |
| | | 14 | 60 | 30 | 60 | | |
| | | 17 | 75 | 34 | 75 | | |
| | | 20 | 90 | 38 | 90 | | |
| | | 24 | 105 | 43 | 105 | | |
| | | 30 | 120 | 48 | 120 | | |
| | | 34 | 135 | 55 | 135 | | |
| | | 39 | 150 | 61 | 150 | | |
| | | 42 | 165 | 65 | 165 | | |
| | | 45 | 180 | 68 | 180 | | |
| | | 48 | 195 | 72 | 195 | | |
| | | 51 | 210 | 75 | 210 | | |
| | | 54 | 235 | 78 | 235 | | |
| | | 56 | 240 | 81 | 240 | | |
| | Total | 136 | Total | 178 | Total | 152 | 174 |
| | Exp. | 10.30 | Exp. | 7.85 | Exp. | 9.20 | 9.05 |

Drainage Rate 14.0

Drainage Rate 16.7

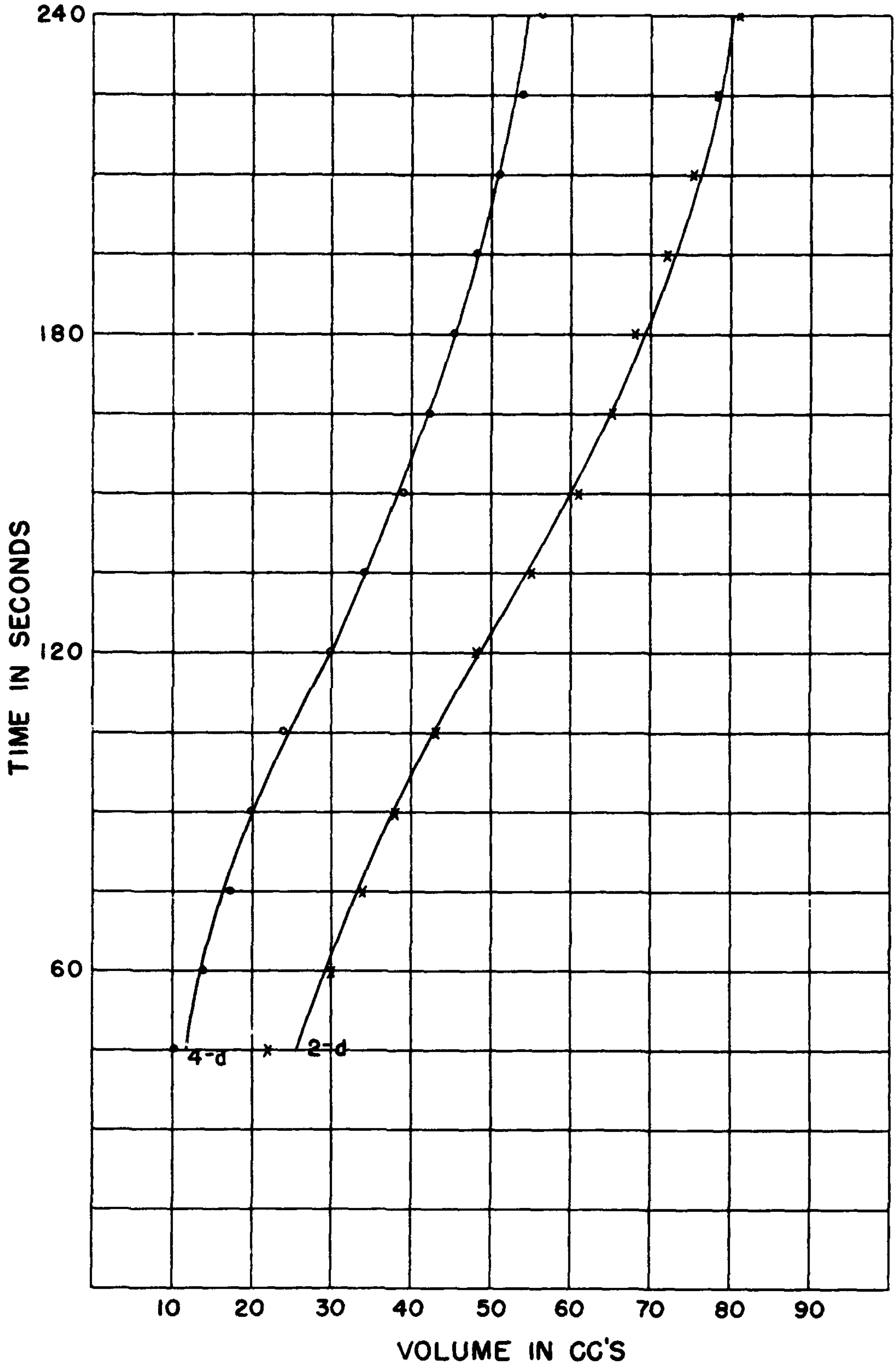
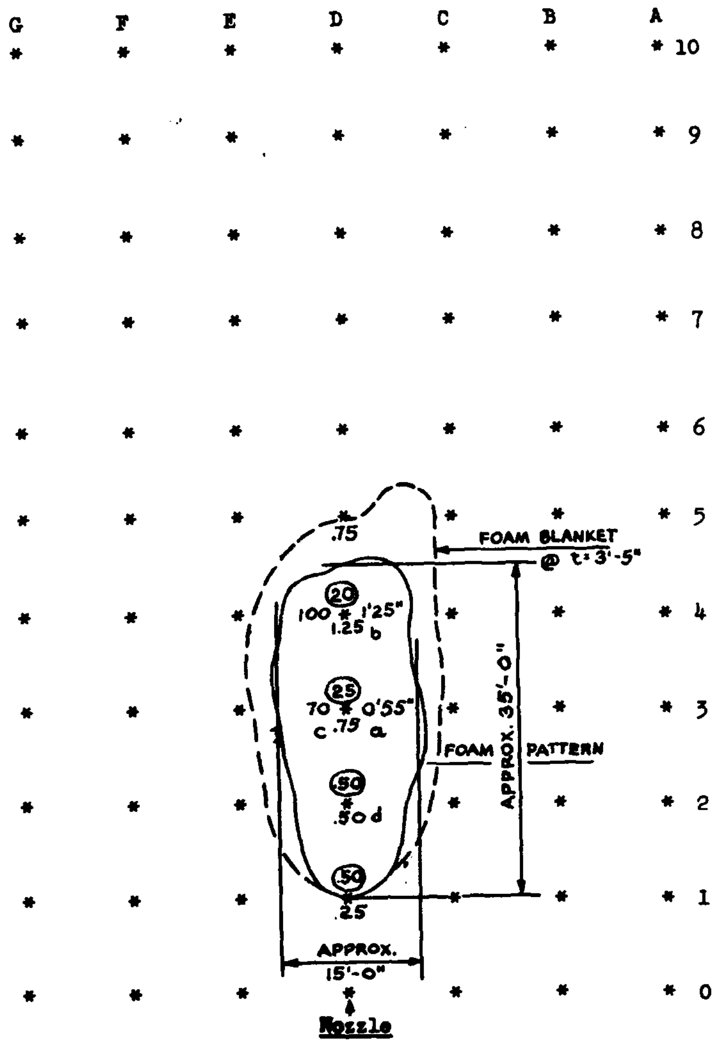



Fig. 32. Foam drainage, run No. 16.

FOG FOAM STUDIES DATA SHEET

Project No. 8-76-01-001 (9)
Date 21 JUNE 1949
Humidity 76%
Temp. during test 85°F
Weather SUNNY, CLEAR
Test area 60' x 100'
Stakes 10' apart

Run No. 17
Nozzle 2 1/2" INTERNAL IMPINGING JET WITH SCREEN




Procedure:
Premix
Metered flow ✓
Pressure:
a. Proportioner 90 psi
b. Nozzles 200 psi
c. Proportioner used 250
Rotometer HIGH RANGE
Water flow 190 gpm
Time of run 0 min 30 sec
Tot. water used 95 gal
Tot. liquid used 7.5 gal
%Foam solution 7.9

Blowup at points below:
a. 5.30
b. 6.10
c. 5.10
d. 6.20
Ave. 5.8

Stability - Min/25% drain
a.
b.
c.
d.
Ave.

% Solution
a.
b.
c.

Area
Pattern 405 $Ft^2$
Blanket 645 $Ft^2$

Ave. Foam Depth
Pattern .113 Ft.
Blanket .059 Ft.

Tot. Foam
Vol. Pattern VP 46.0 $Ft^3$
Vol. Blanket VB 39.0 $Ft^3$
V.E. = 73.5 $Ft^3$

VE = tot. vol. water plus foam liquor times ave. blowup

Eff. $= \frac{VP}{VE} = \frac{46}{73.5} = 62.0\%$

Key
* - Stake
X - Bucket (50 x 3'55")
50cc's drainage - X bucket - 3'55" time after end of foam application

Wind Direction

Velocity 1.0 mph

Data Sheet Recorder J. Allen

FOAM ANALYSIS

By: C. Korzendorfer

Project: 8-76-01-001 (9)

Run No.: 17

Date: 21 June 1949

| Location: | | Drainage 3-D | | 4-D | | Blow up 3-D | 2-D |
|---|---|---|---|---|---|---|---|
| CC's | Time | CC's | Time (sec) | CC's | Time (sec) | | |
| | | 50 | 45 | 22 | 45 | | |
| | | 59 | 60 | 24 | 60 | | |
| | | 66 | 75 | 26 | 75 | | |
| | | 74 | 90 | 30 | 90 | | |
| | | 83 | 105 | 34 | 105 | | |
| | | 94 | 120 | 39 | 120 | | |
| | | 101 | 135 | 45 | 135 | | |
| | | 108 | 150 | 51 | 150 | | |
| | | 114 | 165 | 57 | 165 | | |
| | | 118 | 180 | 62 | 180 | | |
| | | 123 | 195 | 68 | 195 | | |
| | | 127 | 210 | 73 | 210 | | |
| | | 130 | 225 | 78 | 225 | | |
| | | 132 | 240 | 82 | 240 | | |
| | Total | 265 | Total | 232 | Total | 249 | 230 |
| | Exp. | 5.30 | Exp. | 6.10 | Exp. | 5.60 | 6.20 |

Drainage Rate 24.3

Drainage Rate 19.3

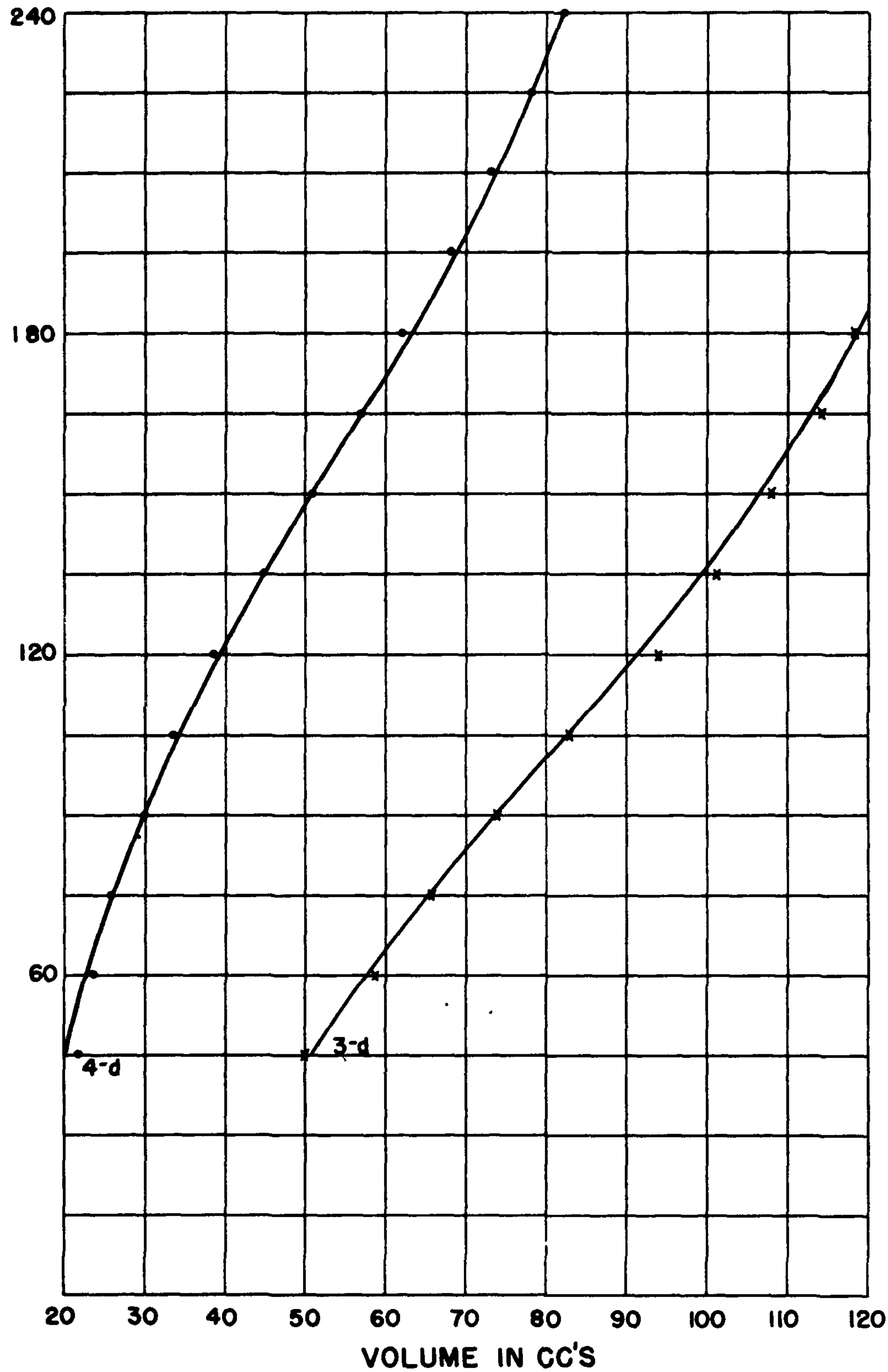
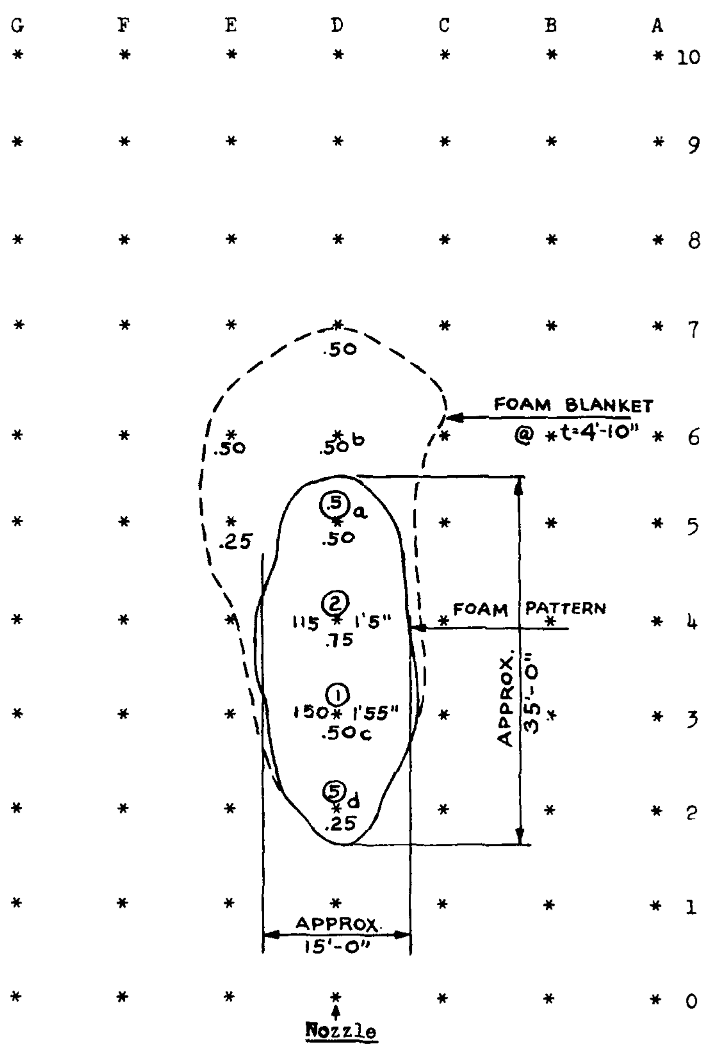



Fig. 33. Foam drainage, run No. 17.

FOG FOAM STUDIES DATA SHEET

Project No. 8-76-01-001 (9)
Date 22 JUNE 1949
Humidity 78%
Temp. during test 87°F
Weather SUNNY, CLEAR
Test area 60' x 100'
Stakes 10' apart

Run No. 18
Nozzle 2½" INTERNAL IMPINGING JET WITH SCREEN




Procedure:
Premix
Metered flow ✓
Pressure:
a. Proportioner 85 psi
b. Nozzles 300 psi
c. Proportioner used 250
Rotometer HIGH RANGE
Water flow 200 gpm
Time of run 0 min 30 sec
Tot. water used 100 gal
Tot. liquid used 7 gal
%Foam solution 7

Blowup at points below:
a. 5.10
b. 5.40
c. 4.75
d. 7.15
Ave. 5.6

Stability - Min/25% drain
a.
b.
c.
d.
Ave.

% Solution
a.
b.
c.

Area
Pattern 485 $Ft^2$
Blanket 910 $Ft^2$

Ave. Foam Depth
Pattern .0833 Ft.
Blanket .0405 Ft.

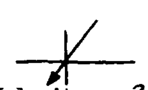
Tot. Foam
Vol. Pattern VP 40 $Ft^3$
Vol. Blanket VB 37 $Ft^3$
V.E. = 76 $Ft^3$

VE = tot. vol. water plus foam liquor times ave. blowup

Eff. $= \frac{VP}{VE} = \frac{40}{76} = 53.2\%$

Key
* - Stake
X - Bucket (50 x 3'55")
50cc's drainage - X bucket - 3'55" time after end of foam application

Wind Direction



Velocity 3.0 mph

Data Sheet Recorder J. ALLEN

**FOAM ANALYSIS**

By: C. Korzendorfer

Project: 8-76-01-001 (9)

Run No.: 18

Date: 22 June 1949

| Location: | | Drainage | | | | Blow Up | |
|---|---|---|---|---|---|---|---|
| | | 5-D | | 6-D | | 3-D | 2-D |
| CC's | Time | CC's | Time (sec) | CC's | Time (sec) | | |
| | | 30 | 45 | 50 | 45 | | |
| | | 35 | 60 | 60 | 60 | | |
| | | 39 | 75 | 66 | 75 | | |
| | | 42 | 90 | 71 | 90 | | |
| | | 47 | 105 | 75 | 105 | | |
| | | 52 | 120 | 80 | 120 | | |
| | | 58 | 135 | 85 | 135 | | |
| | | 64 | 150 | 90 | 150 | | |
| | | 72 | 165 | 96 | 165 | | |
| | | 78 | 180 | 104 | 180 | | |
| | | 83 | 195 | 108 | 195 | | |
| | | 88 | 210 | 112 | 210 | | |
| | | 96 | 225 | 118 | 225 | | |
| | | 104 | 240 | 122 | 240 | | |
| | Total | 270 | Total | 256 | Total | 280 | 195 |
| | Exp. | 5.10 | Exp. | 5.40 | Exp. | 4.75 | 5.15 |
| | | | Drainage Rate 23.0 | | Drainage Rate 20.7 | 4.75 | 7.15 |

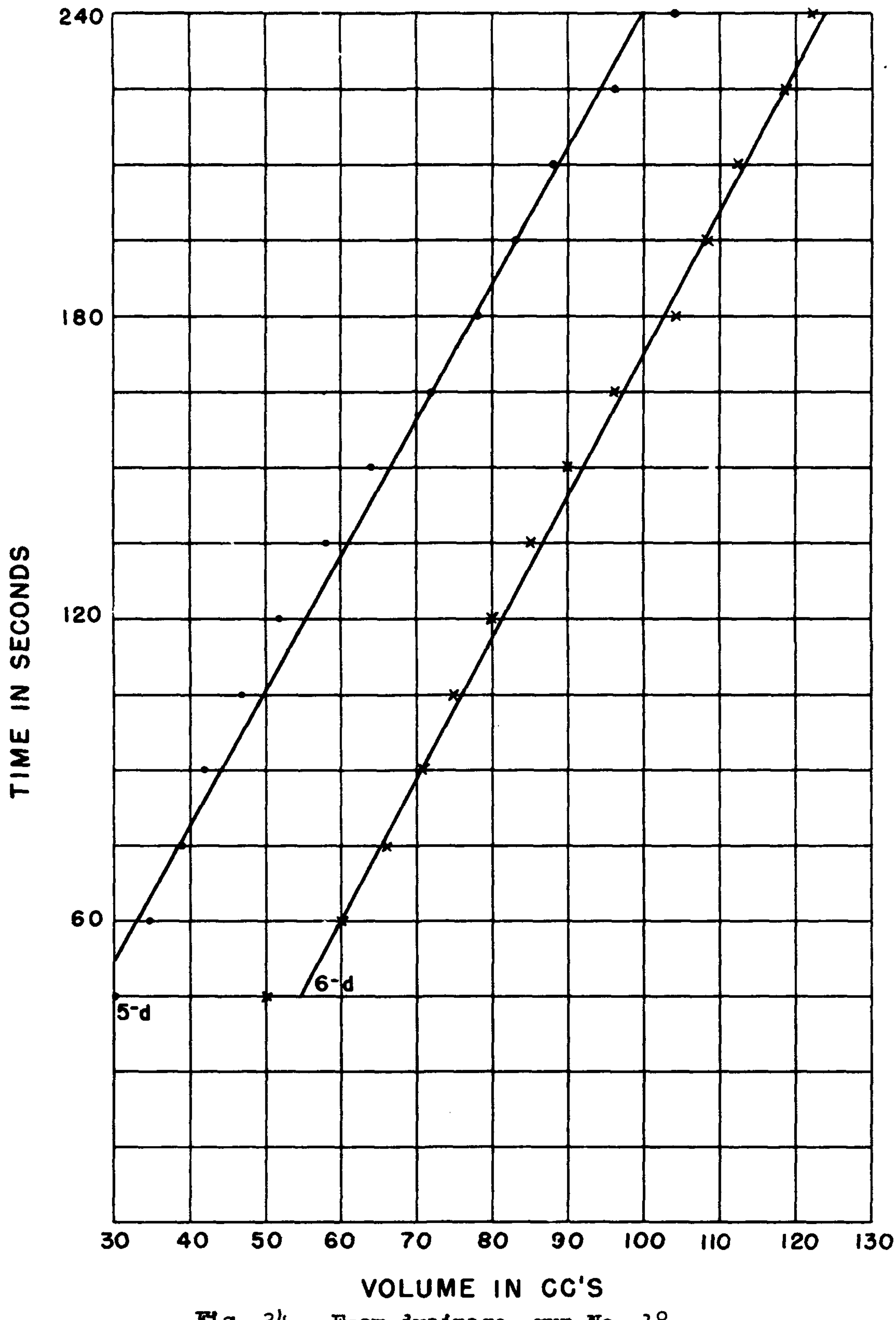
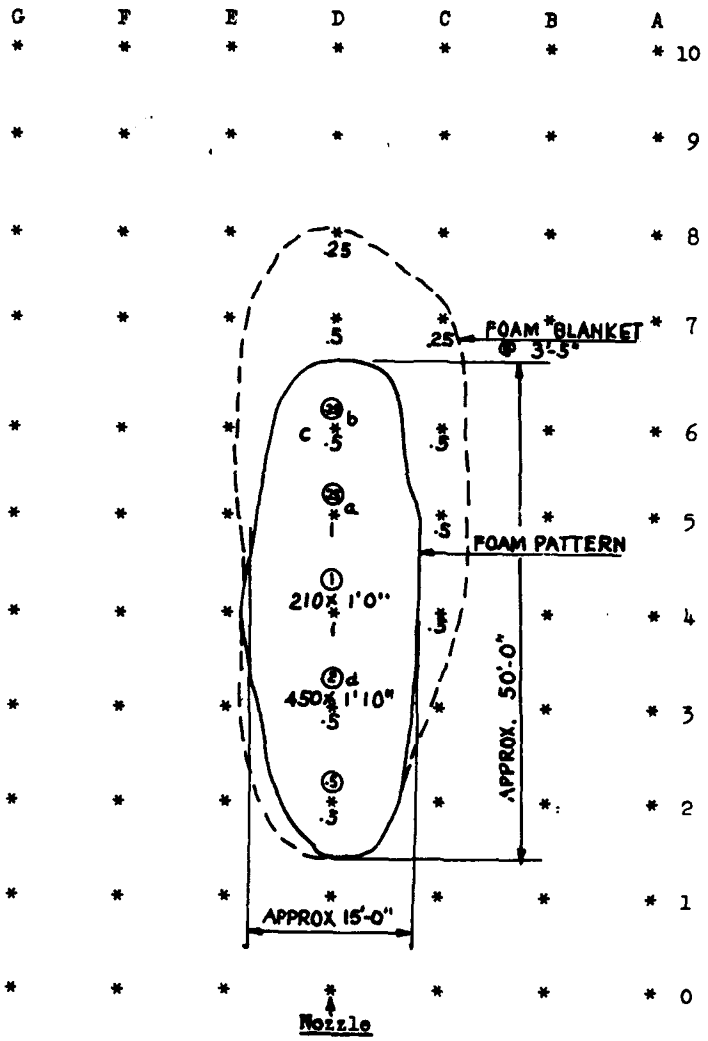


Fig. 34. Foam drainage, run No. 18.

# FOG FOAM STUDIES DATA SHEET

Project No. 8-76-01-001 (9)
Date 22 JUNE 1949
Humidity 79%
Temp. during test 89°F
Weather SUNNY & CLEAR
Test area 60' x 100'
Stakes 10' apart

Run No. 19
Nozzle 2½ INTERNAL IMPINGING JET WITH SCREEN




Procedure:
- Premix
- Metered flow ✓

Pressure:
- a. Proportioner 80 psi
- b. Nozzles 400 psi
- c. Proportioner used 250

Rotometer HIGH RANGE
Water flow 220 gpm
Time of run min 30 sec
Tot. water used 110 gal
Tot. liquid used 7 gal
%Foam solution 6.4

Blowup at points below:
- a. 5.05
- b. 5.65
- c. 7.50
- d. 6.85
- Ave. 6.2

Stability - Min/25% drain
- a.
- b.
- c.
- d.
- Ave.

% Solution
- a.
- b.
- c.

Area
- Pattern 730 $Ft^2$
- Blanket 1150 $Ft^2$

Ave. Foam Depth
- Pattern .065 FT
- Blanket .045

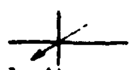
Tot. Foam
- Vol. Pattern VP 47 $Ft^3$
- Vol. Blanket VB 50 $Ft^3$
- V.E. = 91 $Ft^3$

VE = tot. vol. water plus foam liquor times ave. blowup

Eff. $= \frac{VP}{VE} = \frac{47}{91} = 51.6\%$

Key
- * - Stake
- X - Bucket (50 x 3'55")
- 50cc's drainage - X bucket - 3'55" time after end of foam application

Wind Direction



Velocity 2.5 mph

Data Sheet Recorder J. ALLEN

FOAM ANALYSIS

By: C. Korzendorfer

Project: 8-76-01-001 (9)

Run No.: 19

Date: 22 June 1949

| Location: | | Drainage 5-D | | 6-D | | Blow Up 6-D | 3-D |
|---|---|---|---|---|---|---|---|
| CC's | Time | CC's | Time (sec) | CC's | Time (sec) | | |
| | | 55 | 45 | 25 | 45 | | |
| | | 64 | 60 | 32 | 60 | | |
| | | 70 | 75 | 49 | 75 | | |
| | | 73 | 90 | 53 | 90 | | |
| | | 75 | 105 | 55 | 105 | | |
| | | 78 | 120 | 58 | 120 | | |
| | | 81 | 135 | 62 | 135 | | |
| | | 86 | 150 | 66 | 150 | | |
| | | 88 | 165 | 72 | 165 | | |
| | | 94 | 180 | 77 | 180 | | |
| | | 95 | 195 | 82 | 195 | | |
| | | 98 | 210 | 96 | 210 | | |
| | | 102 | 225 | 97 | 225 | | |
| | | 106 | 240 | 100 | 240 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Total | 280 | Total | 247 | Total | 183 | 237 |
| Exp. | 5.05 | Exp. | 5.65 | Exp. | 7.50 | 6.85 |

Drainage Rate 14.0

Drainage Rate 22.7

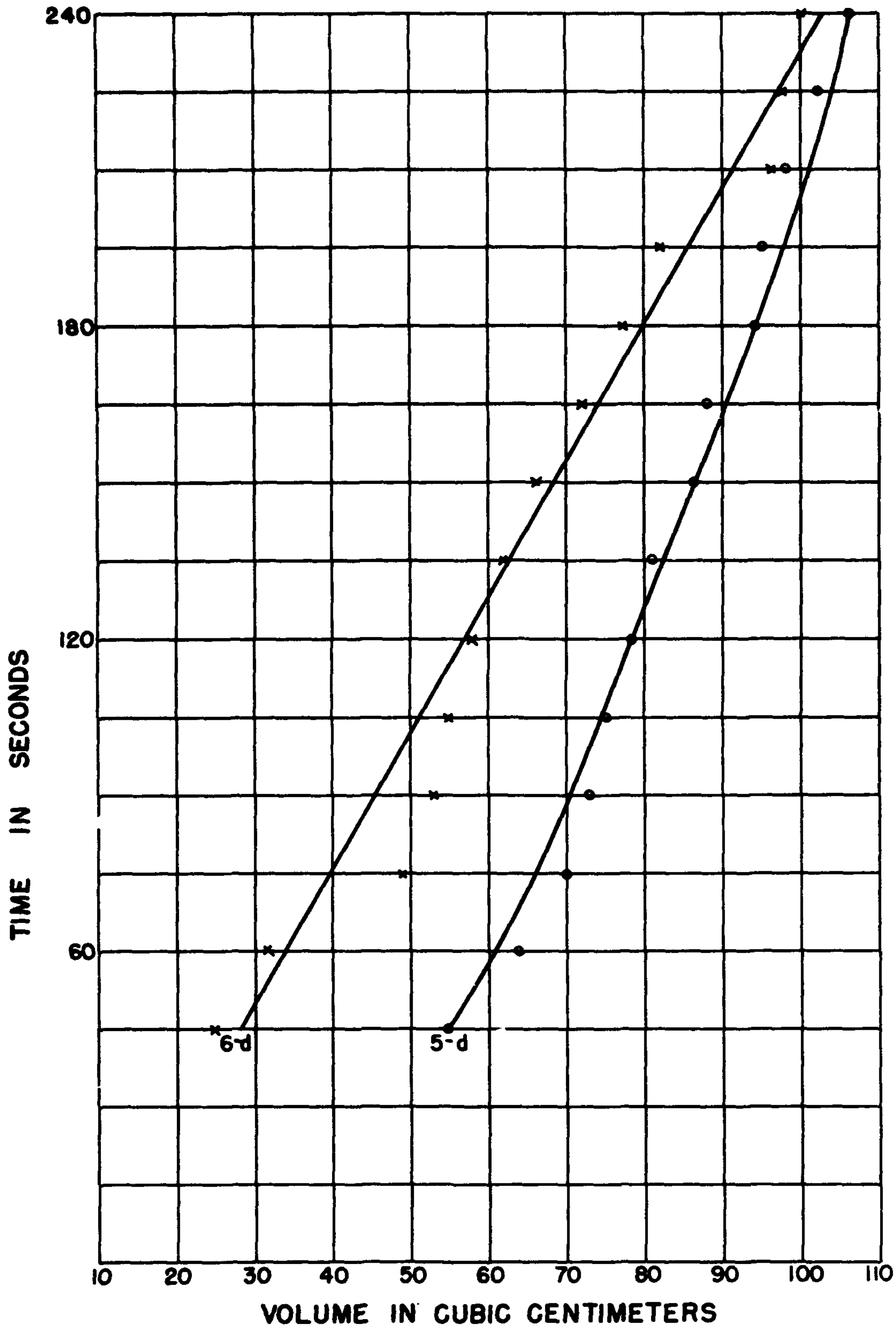
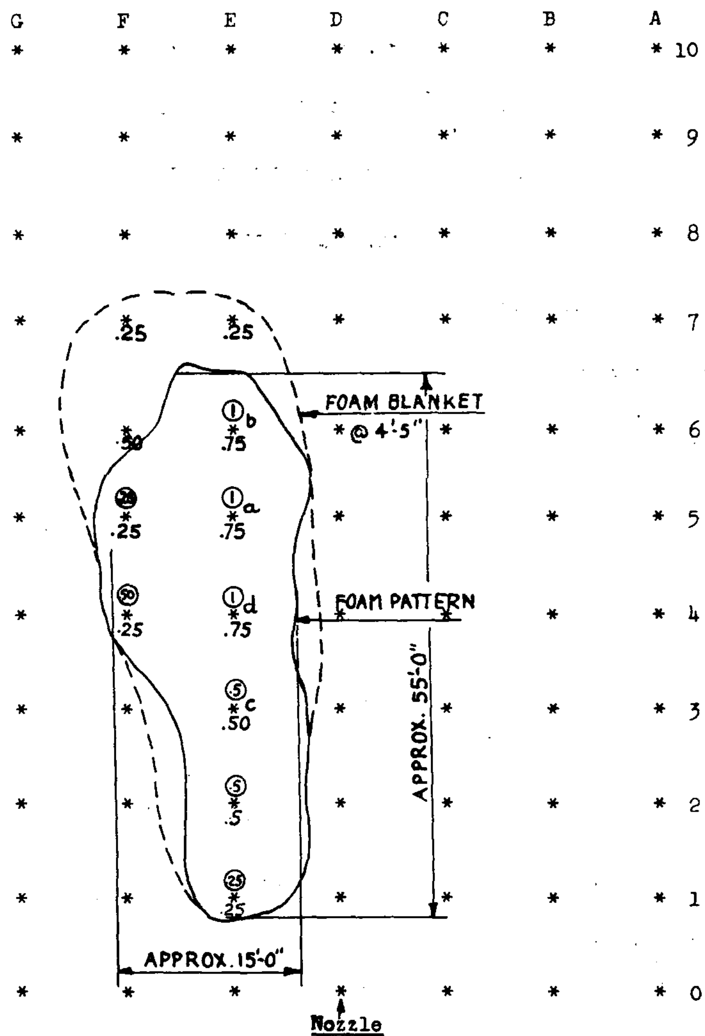



Fig. 35. Foam drainage, run No. 19.

FOG FOAM STUDIES DATA SHEET

Project No. 8-76-01-001 (9)
Date 22 JUNE 1949
Humidity 78 %
Temp. during test 89°F
Weather SUNNY, CLEAR
Test area 60' x 100'
Stakes 10' apart

Run No. 20
Nozzle 2½" INTERNAL IMPINGING JET WITH SCREEN




Procedure:
Premix
Metered flow ✓

Pressure:
a. Proportioner 75 psi
b. Nozzles 500 psi
c. Proportioner used 250

Rotometer HIGH RANGE
Water flow 256 gpm
Time of run 0 min 30 sec
Tot. water used 123 gal
Tot. liquid used 7.5 gal
%Foam solution 6.1

Blowup at points below:
a. 5.20
b. 5.90
c. 5.90
d. 4.90
Ave. 5.5

Stability - Min/25% drain
a.
b.
c.
d.
Ave.

% Solution
a.
b.
c.

Area
Pattern 835 Ft$^2$
Blanket 1220 Ft$^2$

Ave. Foam Depth
Pattern .053 FT
Blanket .037 FT

Tot. Foam
Vol. Pattern VP 45 Ft$^3$
Vol. Blanket VB 45 Ft$^3$
V.E. = 124 Ft$^3$

VE = tot. vol. water plus foam liquor times ave. blowup

Eff. = $\frac{VP}{VE} = \frac{45}{124}$ = 36.3 %

Key
* - Stake
X - Bucket (50 x 3'55")
50cc's drainage - X bucket - 3'55" time after end of foam application

Wind Direction

Velocity 5.2 mph

Data Sheet Recorder J. ALLEN

FOAM ANALYSIS

By: C. Korzendorfer

Project: 8-76-01-001 (9)

Run No.: 20

Date: 22 June 1949

| Location: | | Drainage 5-E | | 6-E | | Blow up 3-E | 4-E |
|---|---|---|---|---|---|---|---|
| CC's | Time | CC's | Time (sec) | CC's | Time (sec) | | |
| | | 26 | 45 | 20 | 45 | | |
| | | 29 | 60 | 25 | 60 | | |
| | | 31 | 75 | 28 | 75 | | |
| | | 33 | 90 | 30 | 90 | | |
| | | 35 | 105 | 32 | 105 | | |
| | | 39 | 120 | 36 | 120 | | |
| | | 45 | 135 | 42 | 135 | | |
| | | 48 | 150 | 44 | 150 | | |
| | | 52 | 165 | 46 | 165 | | |
| | | 57 | 180 | 51 | 180 | | |
| | | 63 | 195 | 55 | 195 | | |
| | | 67 | 210 | 58 | 210 | | |
| | | 74 | 235 | 63 | 235 | | |
| | | 79 | 240 | 67 | 240 | | |
| | Total | 278 | Total | 240 | Total | 240 | 281 |
| | Exp. | 5.20 | Exp. | 5.90 | Exp. | 5.90 | 4.90 |
| | | Drainage Rate 16.7 | | Drainage Rate 14.0 | | | |

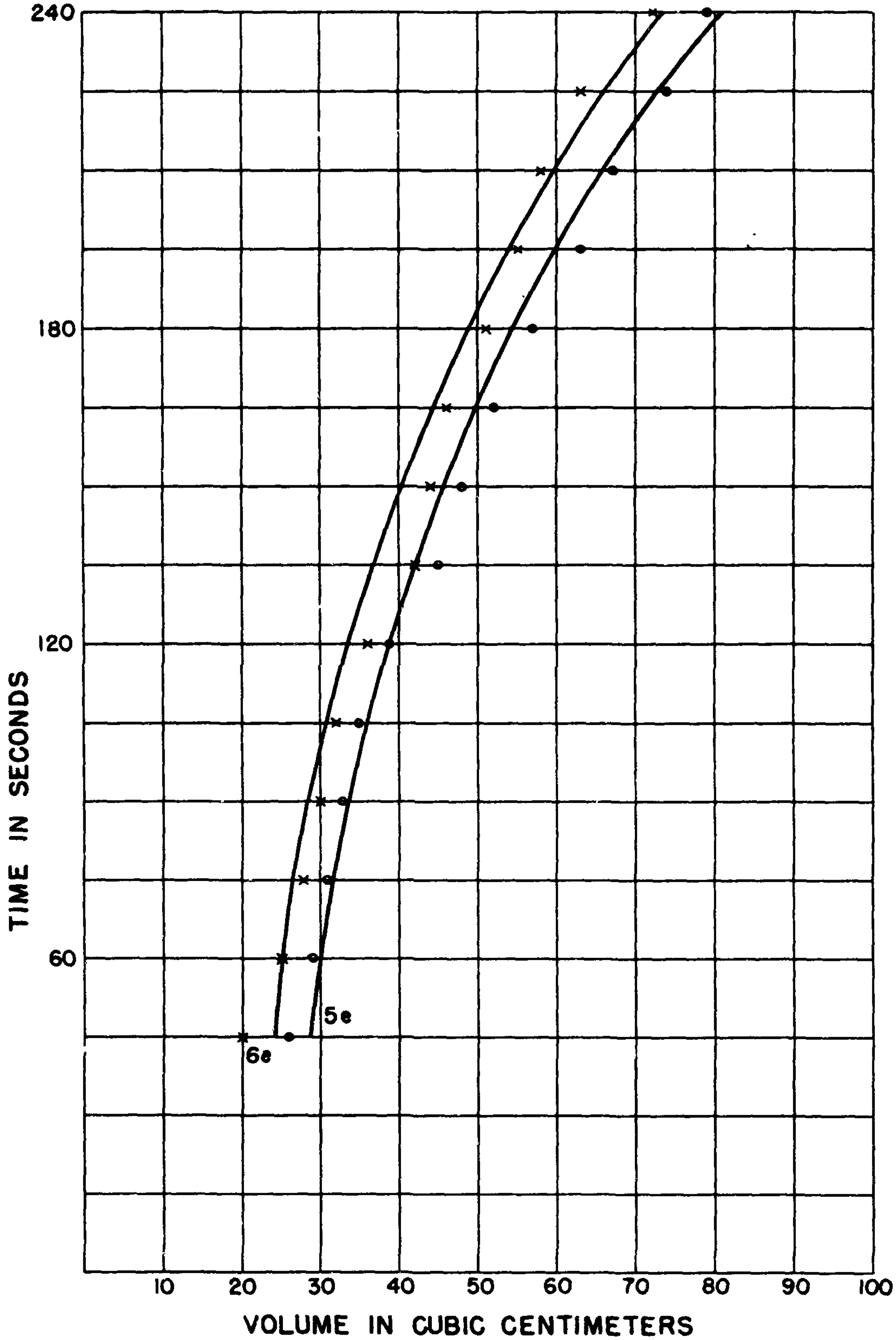



Fig. 36. Foam drainage, run No. 20.

# APPENDIX ID

## WATER FOG DISCHARGE PATTERNS AT DISCHARGE PRESSURES RANGING FROM 100 PSIG TO 500 PSIG

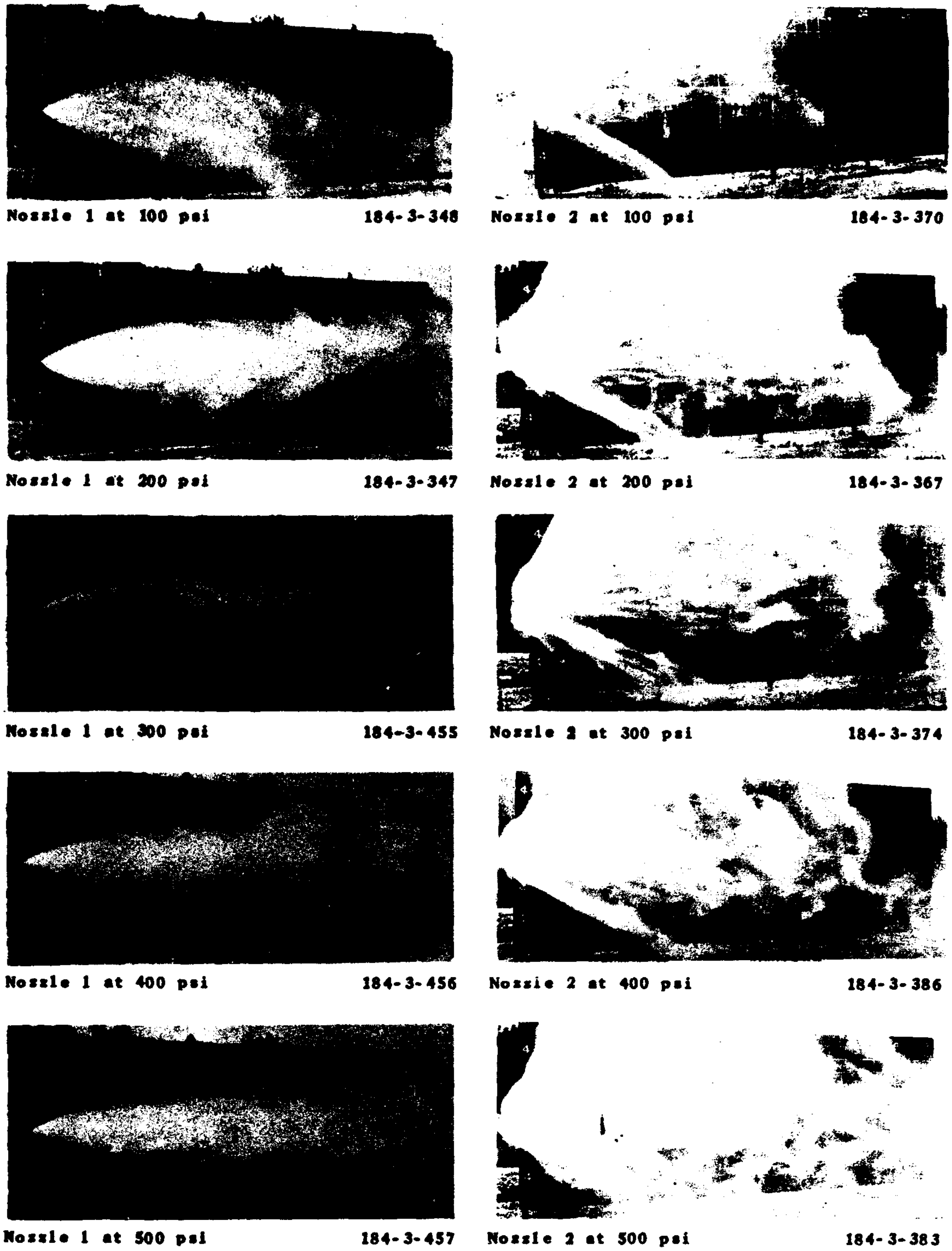



Fig. 37. Water fog patterns obtained at 100 to 500 psig. Left: Nozzle No. 1. Right: Nozzle No. 2.

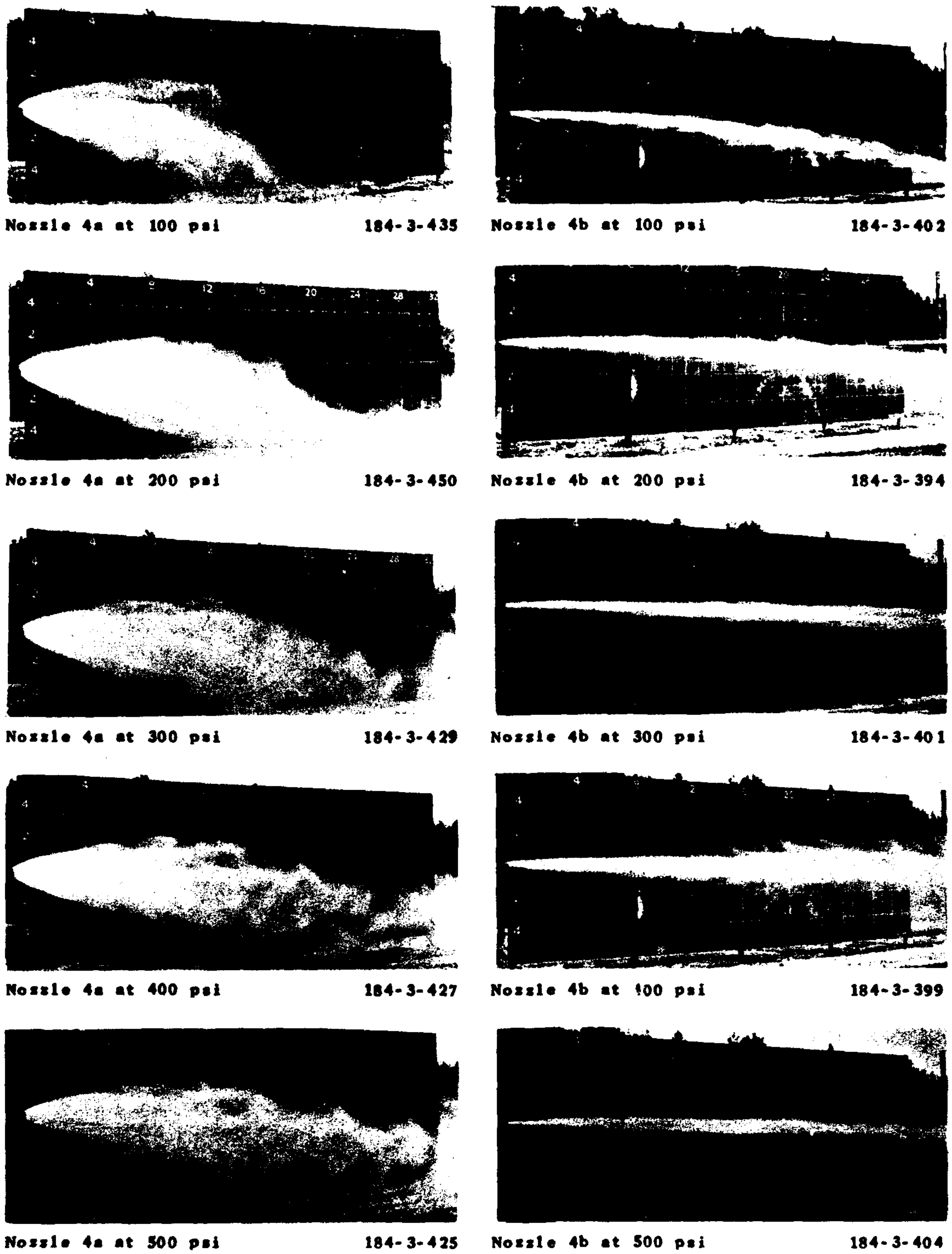



Fig. 38. Water Fog Patterns obtained at 100 to 500 psig. Left: Nozzle 4a with tip A and screen. Right: Nozzle 4b.

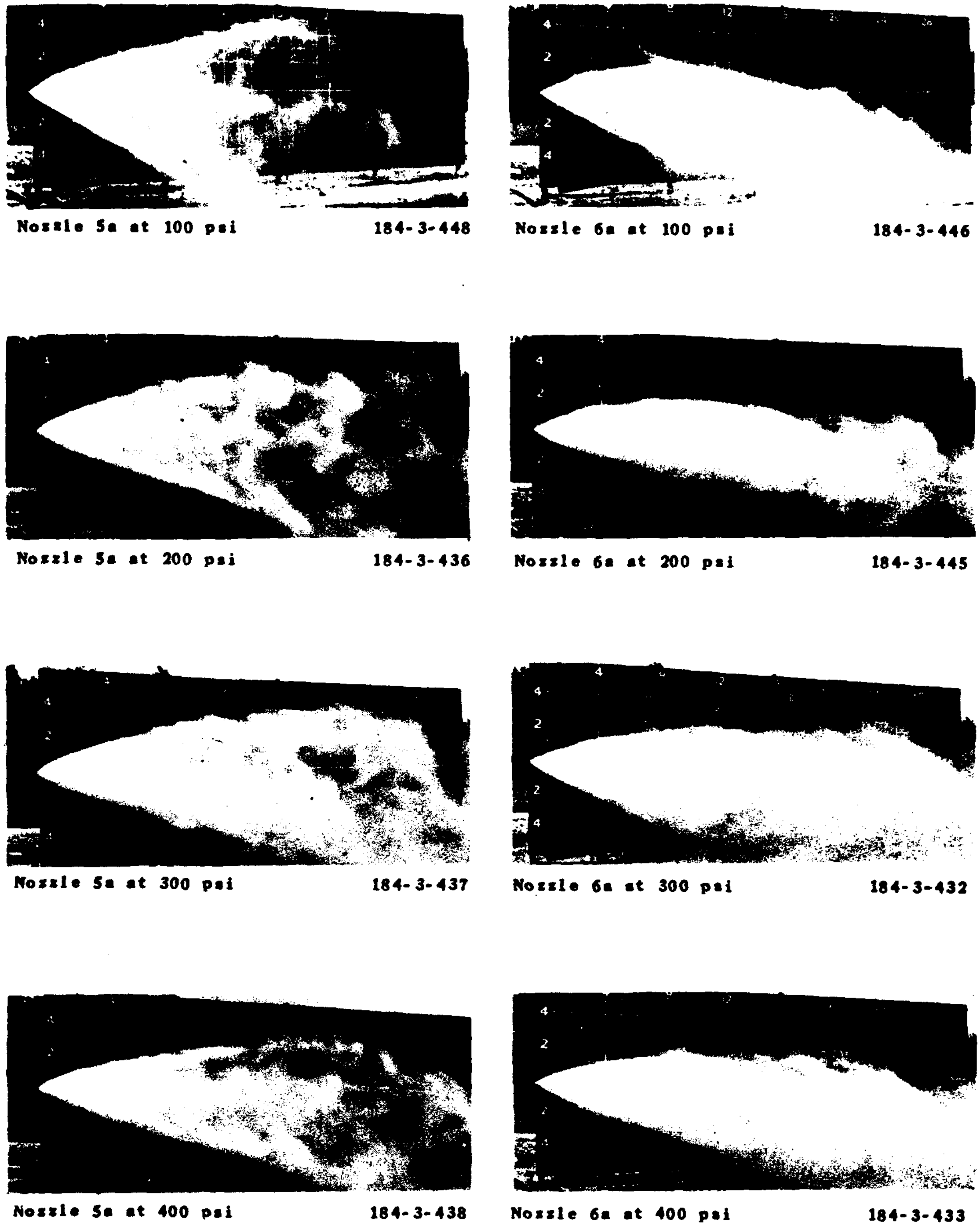



Fig. 39. Water Fog Patterns obtained at 100 to 400 psig. Left: Nozzle No. 5a. Right: Nozzle No. 6a.

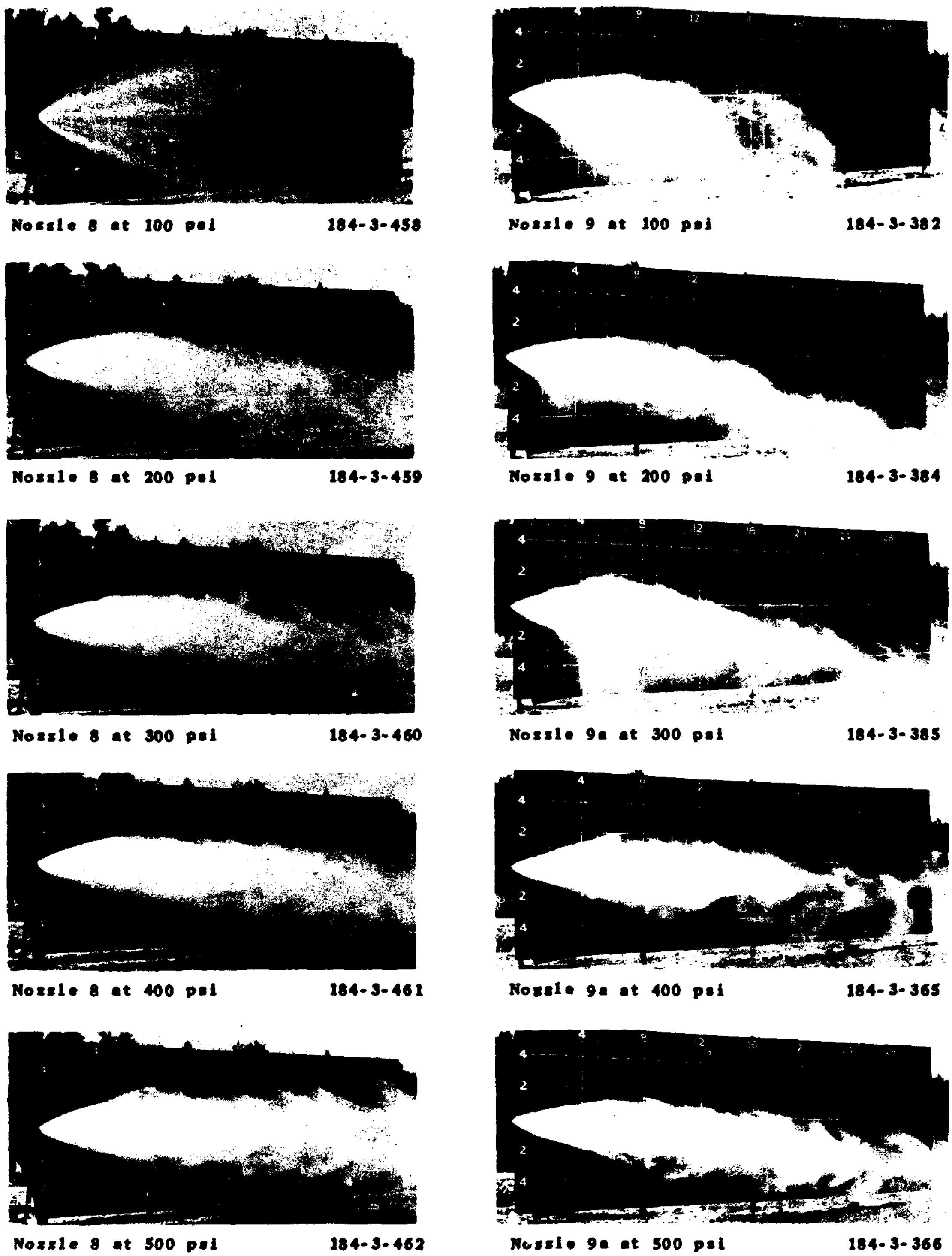



Fig. 40. Water Fog Patterns obtained at 100 to 500 psig. Left: Nozzle No. 2. Right: Nozzle No. 9a.

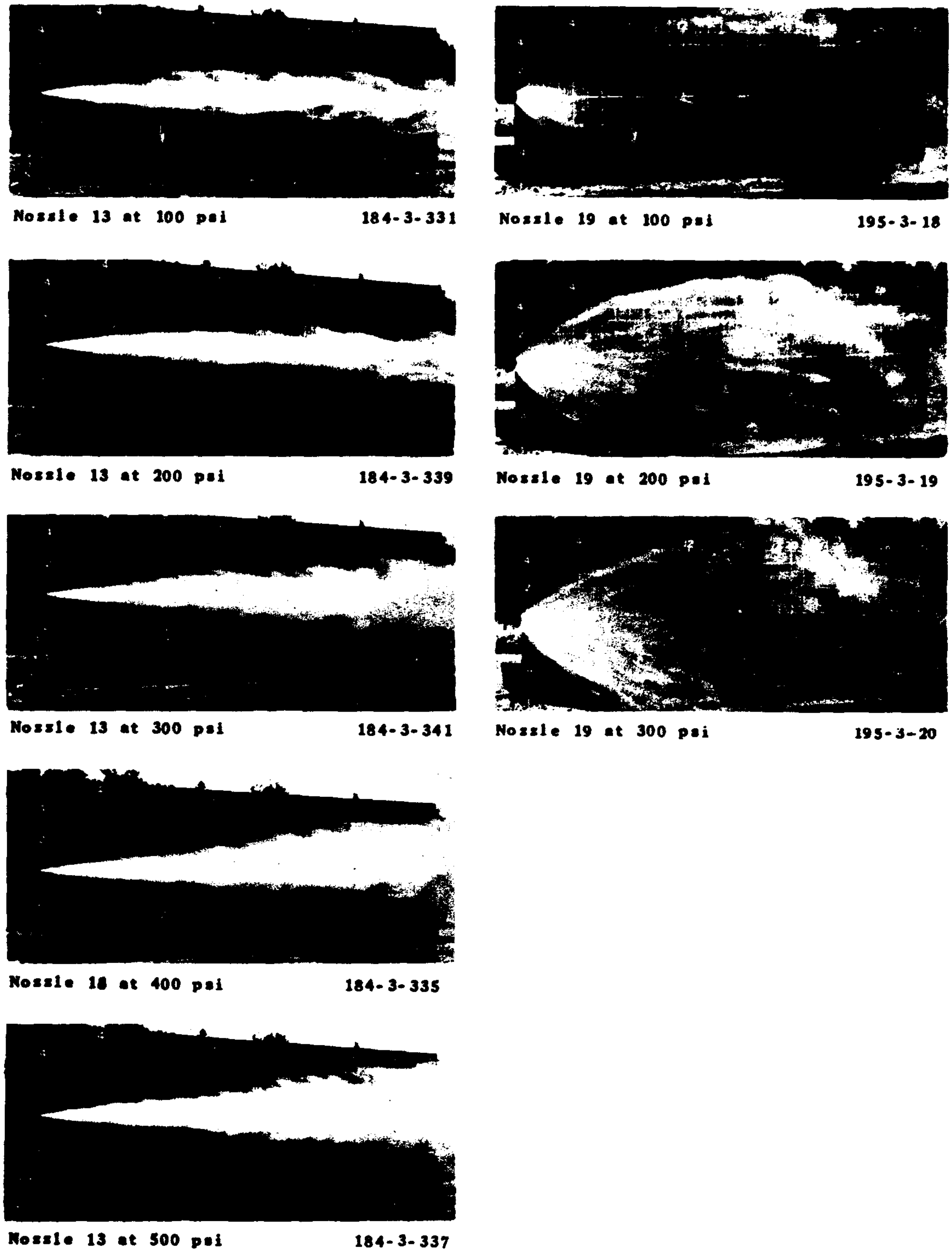
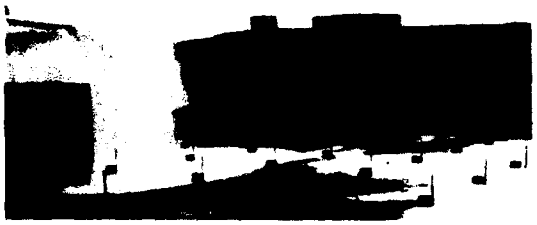



Fig. 41. Water Fog Patterns at various pressures. Left: Nozzle No. 13. Right: Nozzle No. 19 (vertical Pattern)

# APPENDIX IE

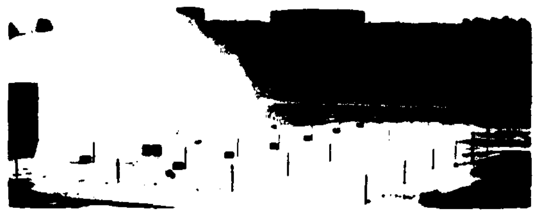
## FOG FOAM SCREENING TESTS



Nozzle 1 Run 1 at 100 psi 184-3-522

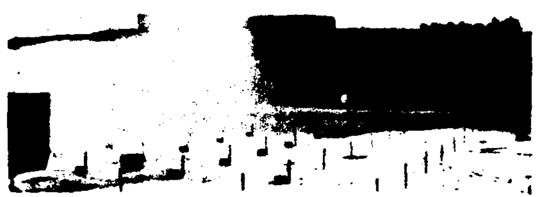
Nozzle 2 Run 6 at 100 psi 184-3-519

Nozzle 1 Run 2 at 200 psi 184-3-523

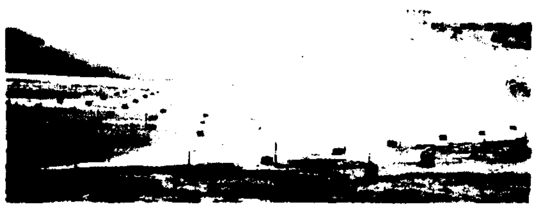


Nozzle 2 Run 7 at 200 psi 184-3-276

Nozzle 1 Run 3 at 300 psi 184-3-524



Nozzle 2 Run 8 at 300 psi 184-3-270



Nozzle 1 Run 4 at 400 psi 184-3-254

Nozzle 2 Run 9 at 400 psi 184-3-520

Nozzle 1 Run 5 at 500 psi 184-3-253

Nozzle 2 Run 10 at 500 psi 184-3-271

Fig. 42. Fog Foam Screening tests. Nozzle Nos. 1 & 2 at conditions noted.

Nozzle 3 Run 11 at 100 psi 184-3-301

Nozzle 11a Run 91 at 100 psi 184-3-733

Nozzle 3 Run 12 at 200 psi 184-3-302

Nozzle 11a Run 92 at 200 psi 184-3-734

Nozzle 3 Run 13 at 300 psi 184-3-595

Nozzle 11a Run 93 at 300 psi 184-3-735

Nozzle 3 Run 14 at 400 psi 184-3-304

Nozzle 11a Run 94 at 400 psi 184-3-732

Nozzle 3 Run 15 at 500 psi 184-3-305

Nozzle 11a Run 95 at 500 psi 184-3-645

Fig. 43. Fog Foam Screening tests. Nozzle Nos. 3 & 11a.


Nozzle 4a Run 16 at 100 psi 184-3-491

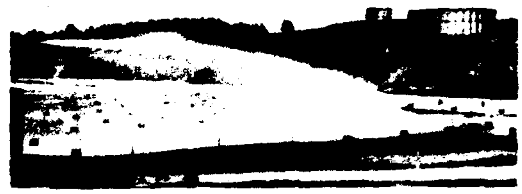

Nozzle 4a Run 17 at 200 psi 184-3-492


Nozzle 4a Run 18 at 300 psi 184-3-493


Nozzle 4a Run 19 at 400 psi 184-3-494


Nozzle 4a Run 20 at 500 psi 184-3-495


Nozzle 4b Run 21 at 100 psi 184-3-540


Nozzle 4b Run 22 at 200 psi 184-3-256


Nozzle 4b Run 23 at 300 psi 184-3-258


Nozzle 4b Run 24 at 400 psi 184-3-539

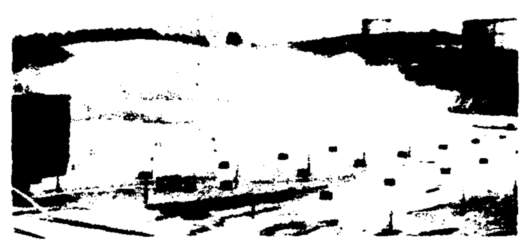

Nozzle 4b Run 25 at 500 psi 184-3-557

Fig. 44. Fog Foam Screening tests. Nozzle Nos. 4a & 4b.

Nozzle 5a Run 36 at 100 psi 184-3-488

Nozzle 5b Run 41 at 100 psi 184-3-501

Nozzle 5a Run 37 at 200 psi 184-3-489

Nozzle 5b Run 42 at 200 psi 184-3-502

Nozzle 5a Run 38 at 300 psi 184-3-490

Nozzle 5b Run 43 at 300 psi 184-3-503

Nozzle 5a Run 39 at 400 psi 184-3-499

Nozzle 5b Run 44 at 400 psi 184-3-504

Nozzle 5a Run 40 at 500 psi 184-3-500

Nozzle 5b Run 45 at 500 psi 184-3-505

Fig. 45. Fog Foam Screening tests. Nozzle Nos. 5a & 5b.

Nozzle 13 Run 106 at 100 psi 184-3-272

Nozzle 19 Run 136 at 100 psi 184-3-764

Nozzle 13 Run 107 at 200 psi 184-3-252

Nozzle 19 Run 137 at 200 psi 184-3-765

Nozzle 13 Run 108 at 300 psi 184-3-590

Nozzle 19 Run 138 at 300 psi 184-3-766

Nozzle 13 Run 109 at 400 psi 184-3-273

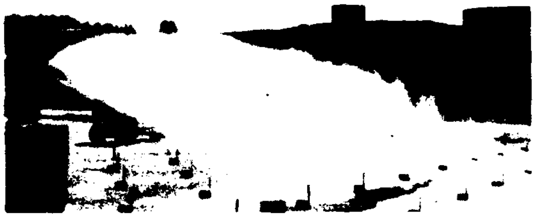
Nozzle 19 Run 139 at 139 psi 184-3-768

Nozzle 13 Run 110 at 500 psi 184-3-250

Fig. 46. Fog foam screening tests. Nozzle Nos. 13 & 19.

Nozzle 14 Run 111 at 100 psi 184-3-260

Nozzle 20 Run 141 at 40 psi 184-3-295

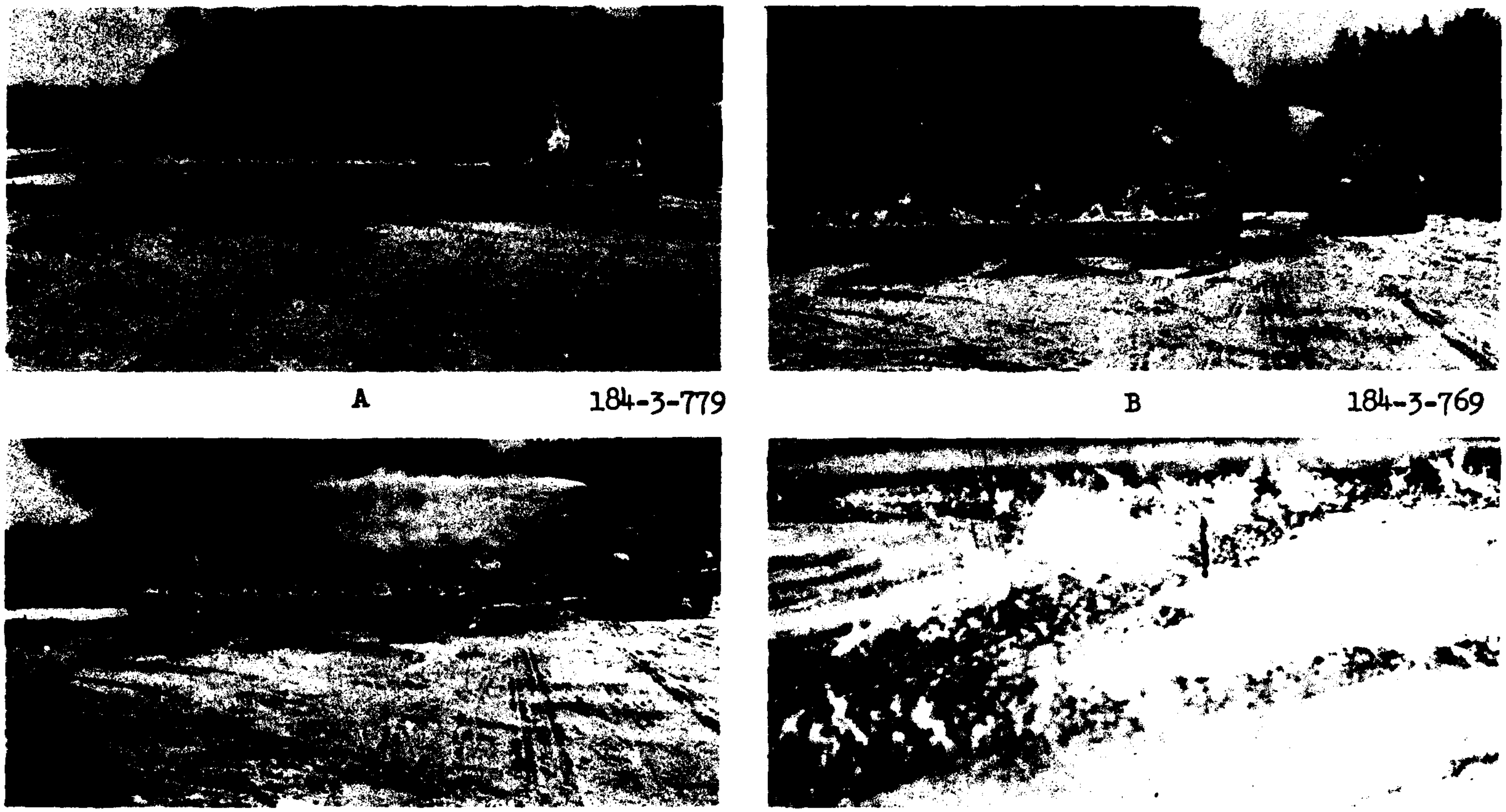


Nozzle 14 Run 112 at 100 psi 184-3-262

Fig. 47. Fog foam screening tests. Left: Nozzle No. 14 at maximum pressure obtainable with test apparatus, approximately 220 psi. Right: Nozzle No. 20 at maximum pressure, approximately 40 psi.

## APPENDIX IF

### ACTUAL FIRE TESTS



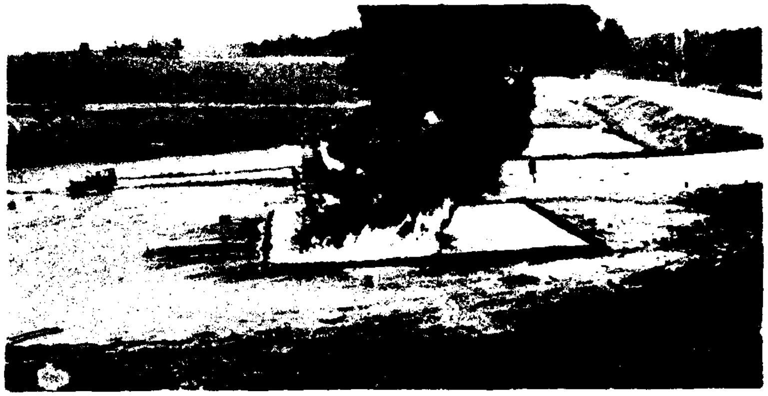
A 184-3-779
B 184-3-769
C 184-3-770
D 184-3-754

Fig. 48. 375-gallon pool fire extinguishment with Nozzle No. 4a. A - Industrial naphtha ignited and fire spreading quickly over entire pool. B - Start of fog foam application after 5 seconds preburn time. C - Foam blanket beginning to take effect approximately 30 seconds after initial application of foam. D - 60 seconds after initial application, foam blanket spreading rapidly and extinguishing remaining fire (close up view).

A 184-3-749

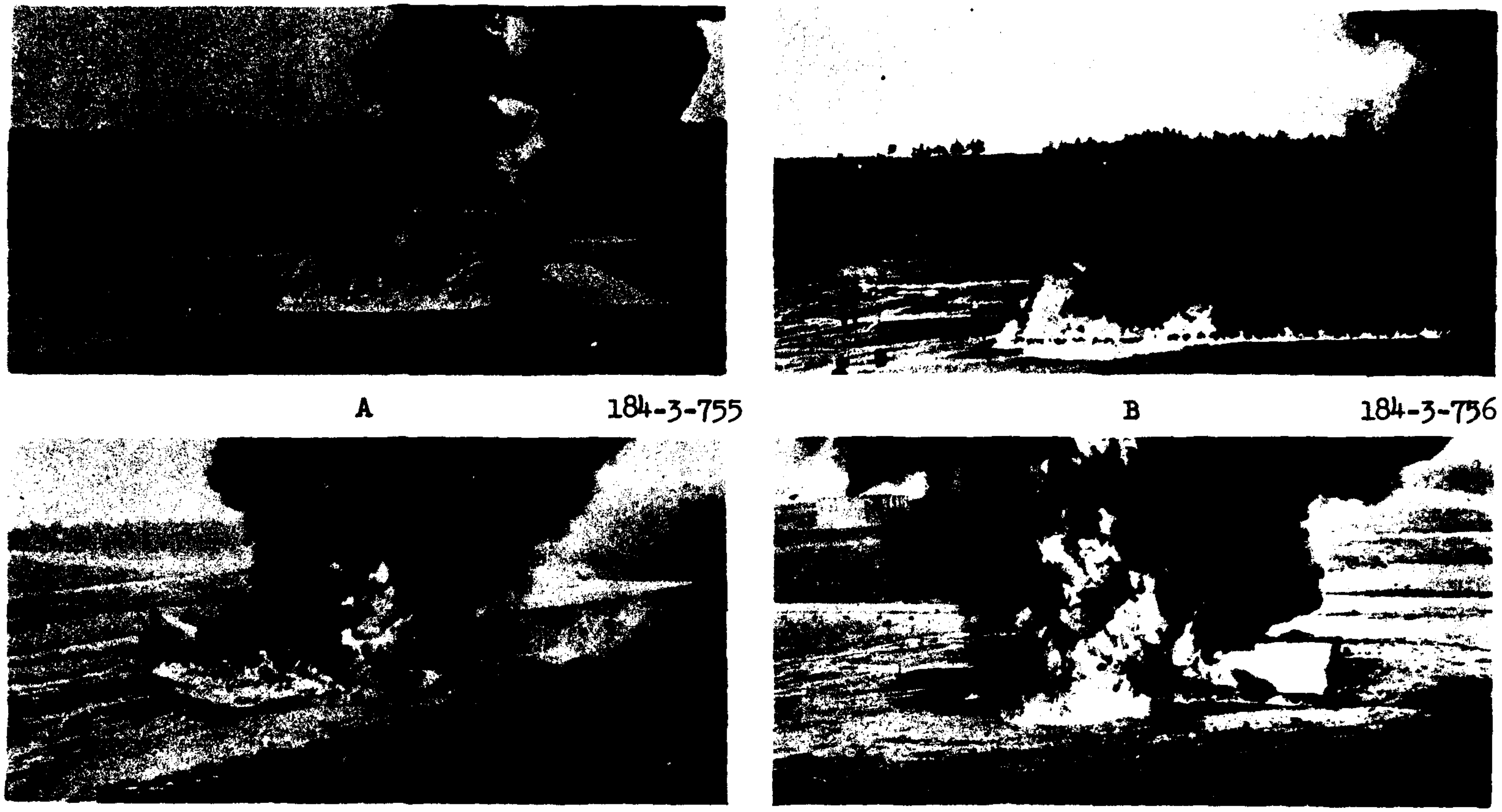
B 184-3-751

C 184-3-753



D 184-3-752

Fig. 49. Attempts to extinguish 375-gallon pool fire with Nozzle No. 1 at 300 psi. A - Fire at height of its intensity after 5 seconds preburn time. B - Initial foam application. C - 120 seconds after initial application, wind direction suddenly shifted. Only very small portion of total area controlled (lower right-hand corner of pool). D - Foam breaking down rapidly and fire regaining its original intensity.



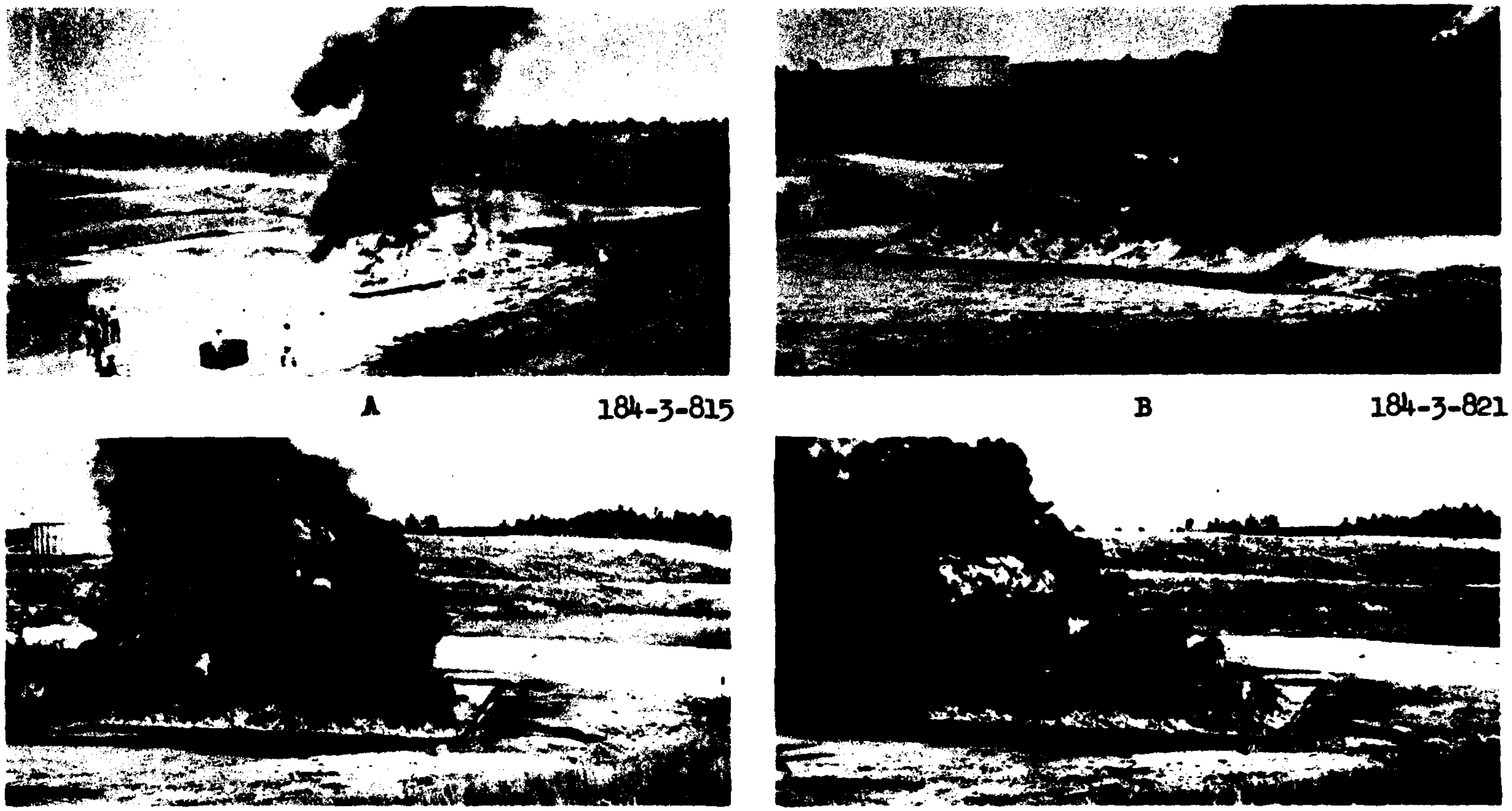
A 184-3-755

B 184-3-756

C 184-3-761

D 184-3-760

Fig. 50. Attempt to extinguish 375-gallon pool fire showing that depression of nozzle more than 15 degrees downward from horizontal plane and increasing nozzle pressure over 300 psi, caused turbulence and splattered burning liquid fuel. A - Initial application of foam at approximately 15 degree angle. B - Fire under control. C - Application angle increased over 15 degrees, inflammable liquid spreading over limits of pool, and fire out of control. D - Fire not extinguished. and spreading rapidly.



A 184-3-815

B 184-3-821

C 184-3-736

D 184-3-737

Fig. 51. Extinguishing 375-gallon pool fire. A - With Nozzle No. 4b. B - With Nozzle No. 13 (nozzle too close to fire, notice foam lost beyond edge of test pit). C - With a short range fog foam nozzle a few seconds after intial application. D - Same test as C, wind velocity increasing suddenly, requiring test truck and crew to be moved to safety.

TITLE: Fog Foam Studies - and Appendixes A-H AD-A281160 - App. 1 AD-A281164 - App. 2

ATI- 82 059

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ABSTRACT:
Tests were performed to determine the effect of hydraulic pressure on the fire extinguishing characteristics of fog foam. Moreover, standards of performance for fog foam nozzles were established experimentally. Fire tests were made with several nozzles having various percent foam yields and nozzle pressures. The nozzles which produced the highest foam yields and had the most effective nozzle pressures for use in fire fighting were ascertained in screening tests by means of a special test procedure. On the basis of the foam used and the nozzle employed, the most effective nozzle pressure was between 200 and 300 psi. Aspirating type nozzles produced higher foam yields than did the nonaspirating type.

* Labs., Fort Belvoir, Va.

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